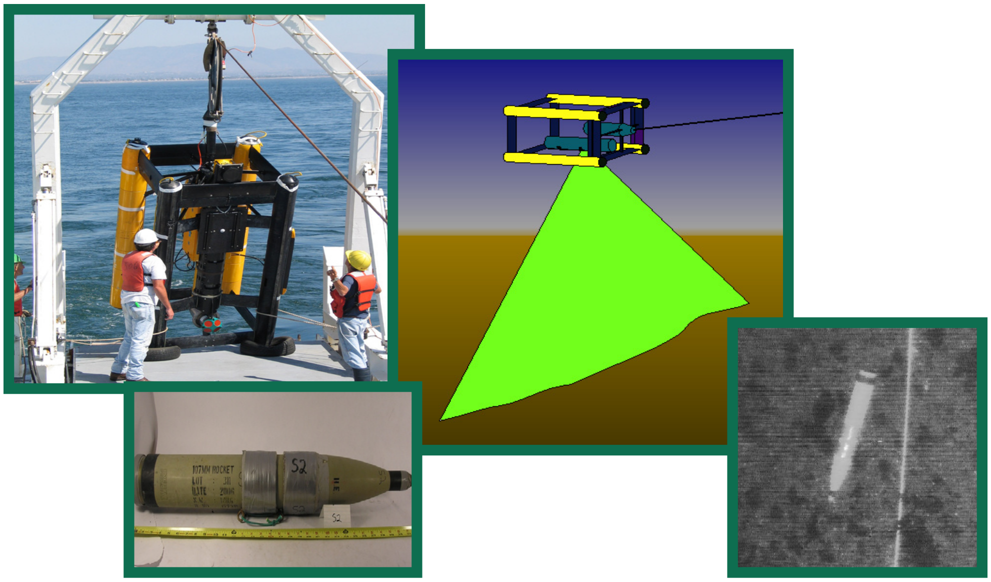
ESTCP
Cost and Performance Report

(MR-200911)



Laser Line Scan System for UXO Characterization

April 2012

ESTCP

ENVIRONMENTAL SECURITY
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ACRONYMS AND ABBREVIATIONS

BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DoD	Department of Defense
DGPS	Differential Global Positioning System
DVL	Doppler Velocity Log
ESS	Explosives Safety Submission
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GAPS	Global Acoustic Positioning System
GPS	Global Positioning System
ha/hr	hectares per hour
HASP	Health and Safety Plan
ID	identification
INS	inertial navigation system
LLSS	Laser Line Scan System
m	meter
MEC	munitions and explosives of concern
m/s	meters per second
MTA	Marine Towed Array
mW	milliwatt(s)
NAVOCEANO	Naval Oceanographic Office
Nd:YAG	neodymium-doped yttrium aluminum garnet
nm	nanometer
OIC	Ocean Imaging Corporation
PHINS	PHotonic Inertial Navigation System
PM	project manager
PMT	photo-multiplier tube
QC	quality control

ACRONYMS AND ABBREVIATIONS (continued)

R/V	research vessel
ROTV	Remotely Operated Towed Vehicle
ROV	remotely operated vehicle
SAIC	Science Applications International Corporation
SCIRC	San Clemente Island Range Complex
SHOBA	Shore Bombardment Area
SPAWAR	Space and Naval Warfare Systems Command
SVP	sound velocity profiler
USACE	U.S. Army Corps of Engineers
USBL	Ultra-Short Baseline
UXO	Unexploded Ordnance
VRS	Virtual Reference Station
WAA	wide area assessment

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All field work and reporting for this project was conducted by Science Applications International Corporation (SAIC) Engineering, Environment and Restoration Division under Contract Number N66001-07-D-0091-0007. The SAIC PM was Dr. Gregory Tracey. Dr. Tracey and his staff were supported by SAIC Vice President Mr. George Seeley and the SAIC Marine Operations Division. The Laser Line Scan System (LLSS), FOCUS Remotely Operated Towed Vehicle (ROTV) and all ancillary survey equipment were provided by SAIC.

Both surveys for this demonstration were conducted aboard the Navy's research vessel (R/V) Acoustic Explorer operated by Rosser Marine & Charter Co., Inc. under the supervision of Captain Bob Rosser. Subsea navigation equipment was provided by IXSEA, Inc., and LLSS software was provided by Ocean Imaging Corporation (OIC).

The Demonstration Plan for this project was developed in coordination with and approved by both the ESTCP's Munitions Management Program Office (Dr. Herb Nelson) and the Navy's Fleet Area Control and Surveillance Facility, San Diego (Mr. John Downey). All operations described in this Final Report were implemented in cooperation with both of these entities.

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1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

Assessments conducted at many former and active Department of Defense (DoD) ranges and installations have discovered unexploded ordnance (UXO) in the underwater environment, posing a potential current or future hazard. Relatively little is known about these underwater sites, which cover a broad spectrum of environments including shallow near-coastal and deep offshore marine sites, as well as estuaries and freshwater sites. This project demonstrates that a remote sensor survey utilizing laser imaging technology can provide an effective means of locating potential UXO in an underwater setting where these items lie exposed on the seafloor. The laser imagery also allows for the determination of size and condition (intact or clutter), which would greatly facilitate the ground-truthing effort or any potential intervention (removal or in-place detonation).

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this project was to demonstrate the utility of the SM-2000 Laser Line Scan System (LLSS) for improved wide-area detection, identification, and assessment of UXO and ordnance-related materials in the marine environment. Under ideal conditions (calm, clear waters; flat topography), the optical images produced by LLSS can georeference and resolve centimeter-sized objects at two to five times the range of conventional video and photographic systems and therefore offer enhanced potential for positive identification and discrimination of UXO items. As a result, the performance of the LLSS was evaluated within a matrix of mission requirements and environmental conditions typical of a range of UXO disposal sites. Three main parameters were selected on which to base the performance evaluation: (1) image quality, (2) target morphometry, and (3) target positioning. Water clarity requirements, in terms of beam attenuation coefficient, for optimal system performance were also evaluated during the demonstration.

1.3 TECHNOLOGY DESCRIPTION

The LLSS is composed of an underwater optical sensor consisting of a solid-state, 200 milliwatt (mW), neodymium-doped yttrium aluminum garnet (Nd:YAG), 532 nanometer (nm) (blue-green) laser with synchronized rotating mirrors and an optical receiver. The light energy reflected by bottom features is projected on a photo-multiplier tube (PMT) and converted into an analog signal. Each individual scan line is passed to the topside electronics where it is digitized and written to file on a sample by sample basis. The LLSS is currently part of an integrated seafloor mapping system residing on Science Applications International Corporation's (SAIC) FOCUS 1500 remotely operated towed vehicle (ROTV). The FOCUS ROTV provides a stable platform that can be maneuvered along discrete survey track lines and provides a coordinated uplink of sensor and instrumentation data over a fiber-optic tow cable manipulated by a LEBUS hydraulic drum winch. High resolution, precision positioning of each seafloor LLSS scan and resulting images are based on data provided by the combined use of the IXSEA Global Acoustic Positioning System (GAPS). The GAPS combines ultra-short baseline (USBL), inertial navigation system (INS) and Global Positioning System (GPS) technologies in one integrated package designed to determine real-time geodetic positioning of an aquatic sensor (i.e., the

FOCUS ROTV) as it moves through the water. Ocean Imaging Corporation (OIC) GeoDAS seafloor imaging and data management software is the primary platform used to support acquisition, real-time processing and geocoding of digital LLSS data and to simultaneously interface navigation, attitude, altitude and environmental sensors providing real-time feedback regarding system operation. Following data acquisition and initial processing with GeoDAS, OIC CleanSweep2 software is also used to provide complete post-survey data processing and quality control (QC) to facilitate the enhancement of LLSS imagery.

1.4 DEMONSTRATION RESULTS

Regarding image quality, LLSS images were found to be sufficient for the purpose of target identification in terms of clarity, contrast, aspect ratio, and visible details. Three LLSS image software platforms (GeoDAS, CleanSweep2, SAIC) were evaluated and showed various differences in final image quality. The images produced by the SAIC software were considered the best overall representation of the targets to be used for final identification.

In terms of target morphometry, the overall length and width LLSS measurements showed good correlation to actual measurements (slope=1.05; r2=0.97, with the regression slope indicating that image measurements were on average 5% larger than actual.

With regard to target positioning precision, data indicated a 50% probability that repeated LLSS-detected target positions would fall within 1.65 meters (m) of the originally measured position and would be no greater than 4 m from the original position at a 95% confidence level. The results also indicated accuracy of 2 to 3 m (depending on which software application was used for measurement) between LLSS determined positions for select targets and “true” positions for the same targets as determined by collocated mobile transponder beacons attached to the targets.

Transmissometer data collected during the Year 2 survey indicated that the LLSS will produce high quality images in bottom water with a beam attenuation coefficient <1.115 m^{-1} and will not produce successful images in bottom water with a beam attenuation coefficient >2.453 m^{-1}. The lowest observed beam attenuation coefficients were correlated to bottom types consisting primarily of rock or sand while the highest observed beam attenuation coefficients were correlated to sandy silt. Divers confirmed the presence of a high turbidity layer concentrated within ~1 m of the bottom during the survey of soft bottom areas.

For the blind testing element, Tier I classification success (target correctly identified as UXO simulator or dummy object) was 89% for targets surveyed. Tier II classification success (specific target identification [ID] correctly identified) was 78%. The probability of false alarm (Type I error; dummy objects falsely identified as UXO simulators) and the probability of false negative (Type II error; UXO simulators falsely identified as dummy objects) were both 0%. These results suggest that the technology is capable of providing accurate target discrimination for objects proud of the seafloor.

Other statistics from the demonstration surveys complied with established success criteria for depth station keeping (±0.8 m of target altitude), line station keeping (<3 m of the target survey line), data preprocessing (45 minutes per 500 m swath of LLSS imagery with georectification), target analysis (2.5 hours per 500 m swath of LLSS imagery), survey coverage (<1.7% survey

area missed) and survey production rate (27,114±3390 m^2/hour for low altitude [3-4 m] pass; 52,705 m^2/hour for high altitude [7-8 m] pass). It should be noted that the probability of surrogate target detection and target location accuracy quantitative objectives were not fully qualified as desired given limitations of the available data resulting from lack of access to the intended survey area at the San Clemente Island Range Complex (SCIRC). The ease of use, system reliability and maintenance qualitative objectives were met within the scope of the available data.

1.5 IMPLEMENTATION ISSUES

There were no environmental or regulatory issues associated with the LLSS demonstration. All operations were non intrusive and thus did not require permits and were not subject to any other local environmental regulations. All activities were overseen by Space and Naval Warfare Systems Command (SPAWAR) and conducted within the constraints of the project specific Demonstration Plan and Health and Safety Plan (HASP), both of which were reviewed and approved by the Environmental Security Technology Certification Program (ESTCP) and Navy prior to initiating work.

The most likely end users of this technology are commercial UXO service provider firms under contract to the DoD. Direct DoD users include Army, Navy, and Marine Corps installation managers who are responsible for training ranges with marine munitions and explosives of concern (MEC) contamination problems. The complete LLSS (including FOCUS ROTV) is the property of SAIC and is housed and maintained at the SAIC Marine Operations facility on Ponderosa Avenue, San Diego, CA. It can be made available to support other demonstrations or marine UXO survey operations. Optional software platforms to perform LLSS image analysis (i.e., CleanSweep2) can be purchased separately or leased prior to any survey activities. No specialized training is required to operate the LLSS aside from company-specific or project-specific health and safety training for both marine offshore and laser operation. However, specialized skills in maintaining and troubleshooting the LLSS, piloting the FOCUS vehicle and operating the LLSS software are necessary to ensure optimal performance, and these skills can only be acquired through prior work with the LLSS technology.

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2.0 INTRODUCTION

This Cost and Performance Report provides an extended summary of the Final Report for the Demonstration of the LLSS for UXO characterization. This demonstration was conducted for ESTCP by SPAWAR Systems Center, Pacific with SAIC.

2.1 BACKGROUND

Assessments conducted at many former and active DoD ranges and installations have discovered UXO in the underwater environment, posing a potential current or future hazard. The U.S. Army Corps of Engineers (USACE) has evaluated Formerly Used Defense Sites (FUDS) and found that there are more than 10 million acres potentially containing munitions and UXO in underwater environments at approximately 400 sites. Additionally, the U.S. Navy and Marine Corps have identified 20 offshore range sites containing munitions. This project demonstrates that a remote sensor survey utilizing laser imaging technology can provide an effective means of locating potential UXO in an underwater setting where these items lie exposed on the seafloor. The laser imagery also allows for the determination of size and condition (intact or clutter), that would greatly facilitate the ground-truthing effort or any potential intervention (removal or in-place detonation).

The LLSS is unique in that it can rapidly collect accurately georegistered, high-resolution images of the seabed and exposed objects resting at the sediment-water interface, thus resulting in considerably enhanced spatial coverage over time. The benefit associated with use of the LLSS as part of UXO surveys is that this system combines the efficiency and spatial coverage of a remote survey system with an image resolution approaching that of visual observations. For objects proud of the seafloor and in waters of sufficient clarity, the system offers the potential for immediate, positive detection of exposed UXO (as opposed to clutter or non-UXO items), thus greatly reducing the total number of validation events that would otherwise be required for UXO surveys based solely on wide area geophysical systems.

2.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this project was to demonstrate the utility of the LLSS for improved wide area detection, identification, and assessment of UXO and ordnance-related materials in the marine environment. Results are based on two surveys (heretofore referred to as Year 1 and Year 2, corresponding to fiscal years) wherein the ability of the LLSS to collect high-resolution digital imagery of the seafloor and discriminate potential UXO was examined. The results of these surveys were intended to demonstrate that the LLSS technology can focus, prioritize, and potentially eliminate the need for follow-on surveys involving more intensive “cued” systems (e.g., electromagnetic) or other ground-truthing efforts (e.g., diver confirmation). The performance of the LLSS was evaluated within a matrix of mission requirements and environmental conditions typical of a range of UXO disposal sites. A series of performance metrics was used for determining the level of success achieved during each phase of the demonstration.

2.3 REGULATORY DRIVERS

The regulatory issues affecting the UXO problem are most frequently associated with the Base Realignment and Closure (BRAC) and FUDS processes involving the transfer of DoD property to other government agencies or to the civilian sector. When the transfer of responsibility to other government agencies or to the civilian sector takes place, the DoD lands fall under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 requires adherence to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provisions. The basic issues center on the assumption of liability for ordnance contamination on the previously DoD-controlled sites. The operations associated with the LLSS demonstration survey were non-intrusive and did not require permits or an Explosives Safety Submission (ESS) and are not subject to environmental regulation. There were no known regulatory issues with this demonstration. The majority of work was conducted within boundaries of Navy training ranges.

3.0 TECHNOLOGY

This section provides an overview of the technology that was demonstrated.

3.1 TECHNOLOGY DESCRIPTION

3.1.1 Laser Line Scan

The SM-2000 LLSS is an optically based swath imaging tool contained within a single, relatively compact pressure housing that can be transported to a worksite and rapidly mobilized on an ROTV for surveying in water depths ranging from 3 to 1500 m. The LLSS is composed of an underwater optical sensor consisting of a solid-state, 200 mW, Nd:YAG, 532 nm (blue-green) laser with synchronized rotating mirrors and an optical receiver (Figure 1). The light energy reflected by bottom features is then projected on a PMT and converted into an analog signal. Each individual scan line is passed to the topside electronics where it is digitized and written to file on a sample by sample basis. As the sensor moves forward, new portions of the seabed are scanned creating a continuous image that is similar in nature to a video image.

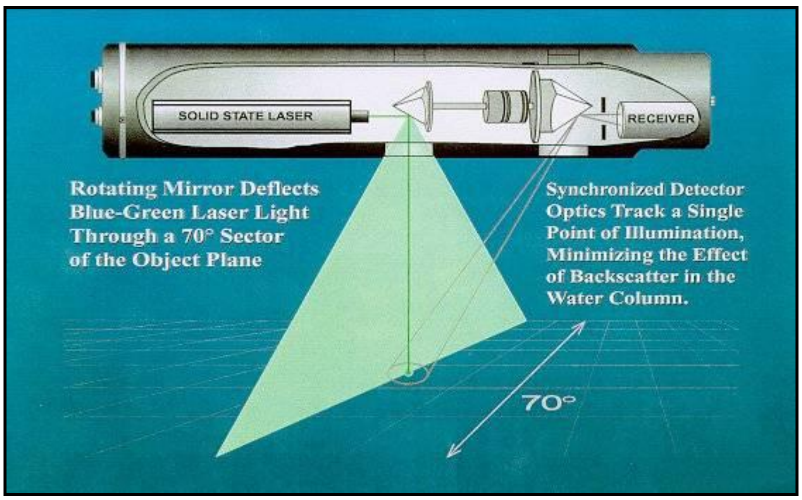

Figure 1. Schematic diagram of the light path of the 532 nm (blue-green) laser during the operation of the SAIC SM-2000 LLSS.

3.1.2 Remotely Operated Towed Vehicle

The LLSS has been engineered to operate independently or within a suite of remote sensors to characterize the seafloor. Currently the LLSS is part of an integrated seafloor mapping system residing on SAIC's FOCUS 1500 ROTV (Figure 2). The FOCUS ROTV provides a stable platform that can be maneuvered along discrete survey track lines and provides a coordinated uplink of sensor and instrumentation data over a fiber optic tow cable manipulated by a LEBUS hydraulic drum winch. The FOCUS is towed behind a vessel of opportunity to provide the vehicle's forward movement at speeds up to 5 knots. It uses four movable control surfaces, two vertical and two horizontal, allowing the operator to control the vehicle position and altitude to within a meter of the desired track.

Figure 2. Photo of the FOCUS 1500 system prior to deployment for an offshore survey with major components identified, as well as dimensions and depth rating for the tow body.

3.1.3 Navigation System

High resolution, precision positioning of each seafloor LLSS scan and resulting images is based on data provided by the combined use of the IXSEA GAPS and the IXSEA PHotonic Inertial Navigation System (PHINS) 6000. The GAPS combines USBL, INS, and GPS technologies in one integrated package designed to determine real-time geodetic positioning of an aquatic sensor (i.e., the FOCUS ROTV) as it moves through the water. The GAPS pressure vessel (i.e., head) features an integrated acoustic array (i.e., hydrophone) and internal gyroscope that is pole-mounted to the survey vessel and lowered into the water at the start of operations. This head is interfaced with a Trimble R8 differential GPS (DGPS) receiver mounted on the deck that obtains the primary position of the survey vessel from which the relative position of the ROTV is calculated by GAPS. As an added component to GAPS, the PHINS unit is mounted directly to the FOCUS vehicle to allow for the three-dimensional motion and independent positioning of the sensor package through the use of an acoustic Doppler Velocity Log (DVL) combined with a second internal gyroscope. The gyroscope provides precise heading, attitude, and heave measurements, while the DVL tracks the motion of the ROTV relative to the seafloor at an update rate of 20 Hz.

3.1.4 Data Acquisition and Processing Software

OIC GeoDAS seafloor imaging/data management software is the primary platform used to support acquisition, real-time processing, and geocoding of digital LLSS data and to simultaneously interface navigation, attitude, altitude, and environmental sensors providing real-time feedback regarding system operation. GeoDAS also allows control of LLSS scan rate, range, aperture, and image balance settings; collects simultaneous navigation streams from GAPS, vessel GPS, and beacons; corrects image display for FOCUS pitch, roll, and yaw; provides a real-time target mark and measure tool; and constructs an image library of flagged targets. Following data acquisition and initial processing with GeoDAS, OIC CleanSweep2

software is also used to provide complete post-survey data processing and QC to facilitate the enhancement of LLSS imagery. This package allows for the smoothing, de-spiking and manual editing of select survey metadata to eliminate spurious features and provides powerful LLSS processing capabilities that include along- and across-track gain equalization. Final data processing with CleanSweep2 provides extensions for porting image data to Esri ArcGIS 9.3 (with Spatial Analyst and 3-D Analyst extensions), which allows LLSS data to be overlaid with other spatial data sets supporting target detection. SAIC has also developed a Microsoft DOS-based LLSS software processing tool that allows for extraction, manipulation, and visualization of raw LLSS data and metadata. The SAIC tool provides additional functionality that is not available within the current versions of GeoDAS and CleanSweep2.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantage of the LLSS over other geophysical instruments is the moderate to high resolution capability, particularly in clear water, that allows for the immediate positive identification of UXO in a wide area assessment (WAA). The primary disadvantage is the inability to image targets in turbid water. Although superior to underwater video in terms of coverage rate, the LLSS is still an optical system with both the source and response light being subject to attenuation during its two-way travel through the water column. The 532 nm light emitted by the laser is substantially more resistant to attenuation than other wavelengths of light in the water column, but its transmission range and energy levels remain a function of water clarity. Particulate matter in the water column scatters both the light emitted from the LLSS, as well as the return signal reaching the PMT. As a result, high concentrations of suspended solids affect the performance of the system.

The LLSS is also sensitive to ambient light conditions in the water column. Despite aggressive light filtering techniques, high levels of ambient light can impact the quality of LLSS imagery, particularly over a shallow water site (<50 ft depth). Ambient light at or near a wavelength of 532 nm is often present in the upper water column during the daylight hours and can produce optical noise that degrades the return signal from the seafloor to the PMT. The degree of signal degradation associated with ambient light is variable based on atmospheric conditions, water color, water clarity, and the depth at which the LLSS is operating.

Relative to other geophysical systems, the LLSS is limited in its ability to detect targets that are buried and potentially surface targets that are significantly fouled; for the latter case the detection limitation is no worse than other optical systems (e.g., underwater video with divers or a remotely operated vechicle [ROV]). The FOCUS vehicle can also support the deployment of a marine magnetometer to address this issue, but this element was not included in the scope of the present investigation.

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4.0 PERFORMANCE OBJECTIVES

The basis for evaluating the performance and costs of the LLSS technology for application to underwater UXO detection is the comparison of final system metrics to pre-determined performance objectives. Both quantitative and qualitative performance objectives were established for the LLSS, as summarized in Table 1.

Table 1. Summary of performance objectives for the LLSS demonstration.

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
Depth station keeping	+/- depth, % of survey length	DGPS and acoustic tracking data	+/- 1 m over 50% survey length
Line station keeping	+/- cross-track position	DGPS and acoustic tracking data	+/- 3 m across track
Data preprocessing and creation of mapped data files	Time	Measured time for processing	<1 hour
Target analysis and dig list time	Time	Measured time from completion of the collection of raw target data	<3 hours
Survey production rates	Acres/day	Measured survey area covered	>42,000 m^2/hour
Probability of surrogate target detection	Target detect frequency (%)	Number of true targets found	>90%
Probability of false alarm	False alarm frequency (%)	Number of dummy objects incorrectly identified as UXO simulators	<10%
Probability of false negative	False negative frequency (%)	Number of UXO simulators falsely identified as dummy objects	<10%
Target location accuracies	x, y position differential (+/- cm)	True position and calculated position of targets	+/-50 cm
UXO parameter estimates	Length, width (cm)	Calculated dimensions and actual dimensions	+/-5 cm
Survey coverage/missed areas	percent total area requiring re-mapping	Area mapped and area missed	<5%
Qualitative Performance Objectives			
Ease of use	Level of effort	1. Feedback from technician on usability of technology and time required	Relative ease
System reliability	Percent down time during surveys	2. Historical data from previous non UXO surveys	<1%
Maintenance	Maintenance per hour of operation	3. Historical maintenance records	<10 min

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5.0 SITE DESCRIPTION

This section provides a summary of the survey sites and includes all site information relevant to the technology demonstration.

5.1 SITE LOCATION AND HISTORY

SPAWAR, in conjunction with SAIC, selected several potential sites in proximity to Naval Air Station North Island and Naval Amphibious Base Coronado in San Diego, CA, for the first LLSS demonstration. Due to a combination of weather and logistical factors, the majority of work during the Year 1 demonstration survey occurred just outside survey area Charlie located south of North Island (Figure 3). Water depths in this area were approximately 70 ft and underwater visibility was reported by divers to be clear during good weather.

Upon revisiting the site selection criteria in conjunction with the results of the Year 1 survey, the SCIRC was chosen as the demonstration area for the Year 2 LLSS survey. This area also offered a wider variety of bottom types (e.g., sand, hard bottom) over which to evaluate system performance. In addition, the San Clemente site represented a heavily used training range with known areas of expended and discarded ordnance present, particularly in the Pyramid Cove and China Point portions of the Shore Bombardment Area (SHOBA) range located on the south shore of the island. These already seeded items could potentially serve as pre-existing “natural” targets for the LLSS demonstration. After mobilization for the Year 2 cruise, however, the project management team received notice that access to the San Clemente Island SHOBA range had been suspended and was ultimately denied. As a result, survey operations were moved to offshore Boat Lanes 7-10 outside Naval Air Station North Island. This area is oriented perpendicular to the shoreline and located northeast of survey area Charlie (Figure 3). The Boat Lanes featured variable seafloor conditions ranging from soft sediment to hard bottom, depending on the exact area, and transmissometer data confirmed that water clarity differed substantially for specific areas within the overall site.

5.1.1 Site History

Naval Air Station North Island is located at the north end of the Coronado peninsula. Since its commission in 1917, this installation has served as the major continental U.S. base supporting operating forces in the Pacific, including over a dozen aircraft carriers, the Coast Guard, Army, Marines, and Seabees. The offshore areas to the southwest of the Coronado peninsula in which the LLSS demonstration was conducted (Figure 3) are subject to vessel traffic supporting the Base. The Boat Lanes, in particular, serve as discrete locations for large ships to anchor while they are awaiting activities. There is no record of significant bottom disturbance or munitions contamination in this area resulting from military operations at North Island or Coronado.

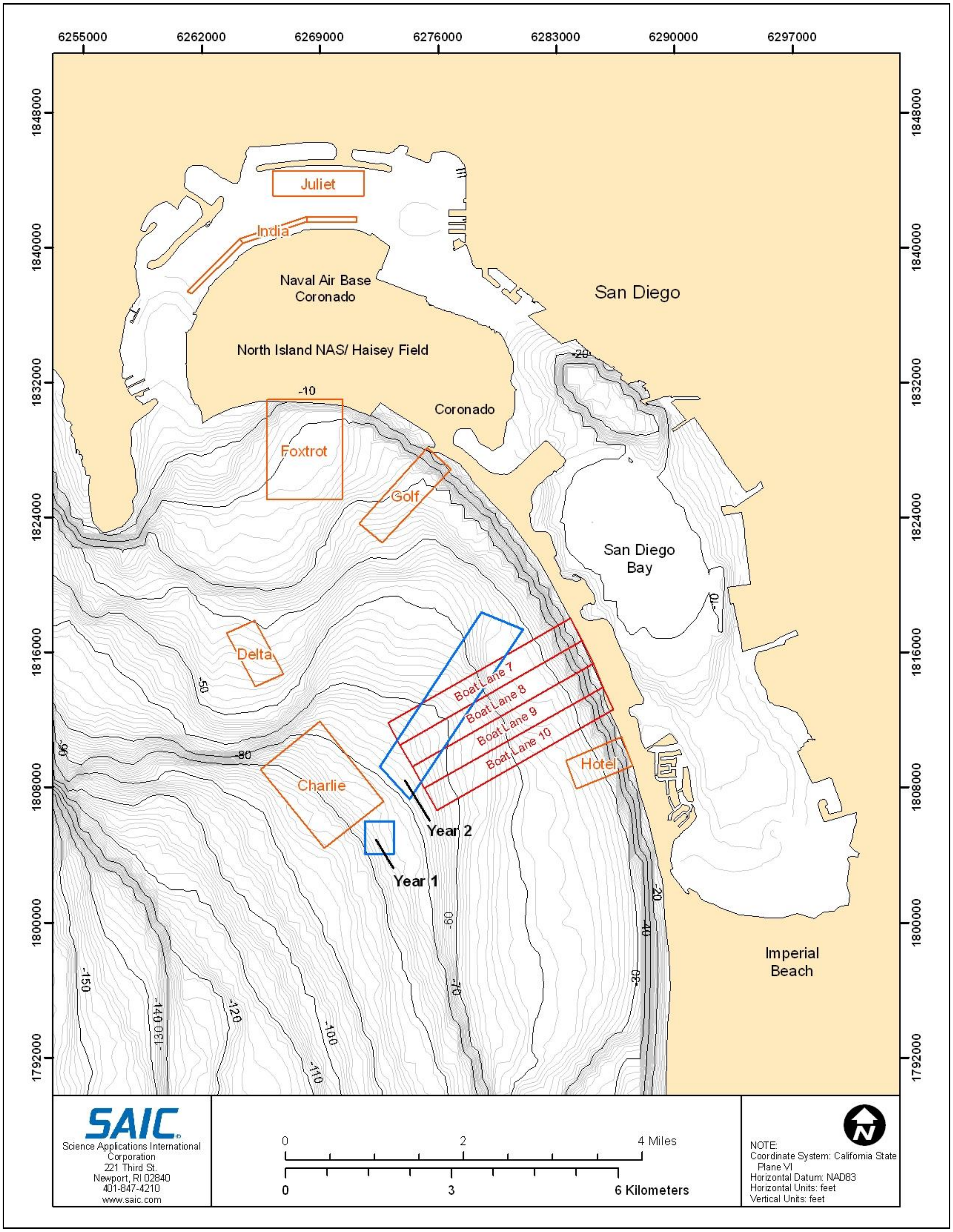

Figure 3. Map showing the location of seven potential survey areas relative to Naval Air Station North Island and the specific LLSS operation areas for the Year 1 and Year 2 surveys.

5.2 SITE GEOLOGY

Surface geology off the coast of San Diego had been well characterized prior to this demonstration by a Naval Oceanographic Office (NAVOCEANO) survey designed to classify the marine environment by mine warfare doctrinal bottom type category. This classification system is intended to provide a probability of detection for mine counter measure systems depending on bottom composition, the estimated percent of mine case burial, and density of bottom clutter, but for the purposes of the LLSS demonstration it served as a good indicator of the bottom types (e.g., hard or soft) to be expected in the survey areas. Bottom types for the LLSS survey areas as reported by NAVOCEANO are shown in Figure 4.

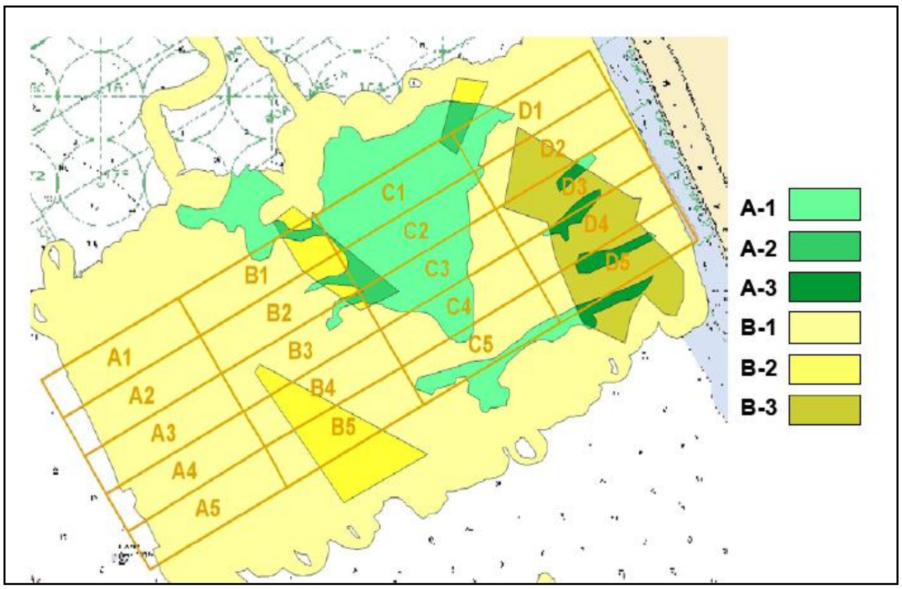

Figure 4. NAVOCEANO doctrinal bottom type classifications for the LLSS demonstration site.

5.3 MUNITIONS CONTAMINATION

No munitions contamination was found to be present in the Year 1 survey area adjacent to survey area Charlie or in the Year 2 survey area in Boat Lanes 7-10. Because the LLSS demonstration was not conducted at San Clemente Island (the site of known expended or discarded munitions items, particularly at the SHOBA range), encountering munitions was not expected during the field effort. Regardless, the LLSS does not come into direct contact with the seafloor and thus any munitions it might have encountered would not have been handled or disturbed in any manner during survey operations.

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6.0 TEST DESIGN

This section provides a detailed description of the survey design that was originally proposed for the LLSS demonstration as well as a summary of the actual accomplishments for each survey year.

6.1 CONCEPTUAL EXPERIMENTAL DESIGN

A robust system-testing regimen was developed to evaluate the performance of the LLSS. This test design required the deployment of a series of inert UXO test objects in pre-established survey areas. The simulated UXO targets ranged in size, shape, and optical reflectance and mimicked a broad spectrum of ordnance-related objects that would be encountered in the marine environment. The simulators were purchased "as-new," so the physical condition when surveyed did not reflect decades of exposure to seawater/fouling communities that would be expected for "real" UXO items. The overall survey effort was designed to have a calibration and a validation testing element in order to gather sufficient data to draw the necessary conclusions regarding system performance.

As part of the experimental design, all data for individual parameters of interest (e.g., target image quality, target measurement, and target positioning) would ultimately be assimilated in a "big picture" manner to evaluate the general ability of the LLSS to correctly distinguish targets under two main classification scenarios: (1) shape as unique identifier and (2) size as unique identifier. Under the first scenario, two targets would have a similar size (<2-inch difference), but one would be a UXO item while the other a similar looking non-UXO item. In this case, LLSS image quality is more important than measuring capabilities for making accurate target identification. High image quality is needed to distinguish target shape (e.g., tapered versus blunt) as well as view unique identifiers (e.g., banding, writing) present on the object. Under the second scenario, two targets would have similar shape, color, and banding, and both would be UXO items. However, these targets would be significantly different sizes (>2-inch difference). In this case, LLSS measuring capabilities are more important than image quality and accurate measurements to less than 1 inch would be needed from the LLSS software to make the proper target identification.

6.2 SITE PREPARATION

The nature of underwater work planned for this demonstration project did not require site preparation beyond the deployment of the targets immediately prior to LLSS operations. Targets were configured on a string consisting of a 1500 ft length of braided line to which loops had been added at approximately 75 ft intervals for target attachment. The targets for this survey consisted of nine inert UXO simulators designed to visually mimic real munitions items ranging from the 155 mm projectile to the 70 mm rocket to the 60 mm mortar (Figure 5). Also included were 11 similarly sized dummy objects (pipes of varying length, diameter, composition, and color designed to mimic the UXO simulators). The UXO simulators were purchased new in "ready-to-use" condition from the U.S. Army Aberdeen Test Center; however, some slight modifications were necessary in terms of adding the mounting points, labels, and weights required for underwater use. The dummy objects were created from materials purchased at a local hardware store. As an added measure of assessing the contrast and optical resolution of the system, an

image of the ISO 12233 electronic image optical resolution chart enlarged to 36×58 inches was mounted onto a 0.050-inch thick (16 gauge) aluminum sheet with spray adhesive and also attached to the target string for imaging by the LLSS (Figure 6).

Figure 5. Inert UXO simulators of a 155 mm projectile (left), 70 mm rocket (middle), and 60 mm mortar (right) used as targets to mimic real munitions items for LLSS calibration and validation elements.

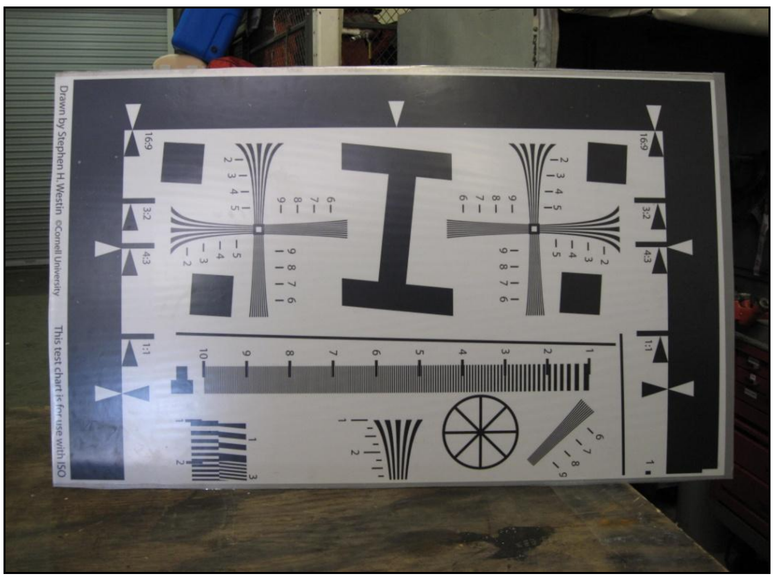

Figure 6. Photograph of the ISO 12233 electronic image optical resolution chart mounted to an aluminum board to be used as part of the calibration survey element.

6.3 SYSTEM SPECIFICATION

The following hardware was used for LLSS operation and navigation during the two LLSS cruises:

- SM-2000 LLSS
- FOCUS ROTV 1500
- LEBUS Hydraulic Drum Winch
- IXSEA GAPS
- IXSEA PHINS 6000

- EdgeTech 2200-M Modular Sonar System with full spectrum dual frequency 120/410 kHz side scan sonar
- Mesotech altimeter
- Trimble R8 DGPS receiver
- Virtual Reference Station (VRS) network

The following software applications were used for data acquisition and processing (both in real time and post-processing) during the LLSS demonstration:

- GeoDAS (data acquisition/real time processing)
- CleanSweep2 (post-processing)
- Hypack (navigation)
- EdgeTech DISCOVER (side scan)

6.4 CALIBRATION ACTIVITIES

6.4.1 Proposed Methodology

According to the approved test plan, the calibration element of the proposed LLSS demonstration was to consist of performing an LLSS survey during a 4-day field effort to collect imagery over a 1500 ft (0.25 nautical mile) string of attached targets that would represent potential UXO and non-UXO items to be encountered on the seafloor. At the beginning of each survey for a selected area, a main line (1-inch nylon braid) containing ~20 attached targets (nine UXO, 11 dummy, and one optical resolution chart) at ~75 ft spacing was to be deployed at a predetermined location by the target team.

6.4.2 Actual Accomplishments

During the Year 1 calibration survey, replicate passes were made over the target line deployed just outside survey area Charlie (Figure 3) with independent piloting of the FOCUS vehicle successful in keeping the entire array in view. Individual shapes and the optical resolution chart could be clearly identified during each pass and were marked in real time using the GeoDAS software. The target string was left in place following data acquisition to facilitate further survey activities the following day. Foul weather conditions for the next two days precluded survey operations so the string remained at the same location.

On the final day of the Year 1 survey, after some improvement in sea state, survey operations were resumed. Divers were used to obtain the precise position of targets on the calibration string by swimming the line with an acoustic beacon in communication with the IXSEA transducer and stopping at individual objects. The diver determined object positions were recorded and ultimately compared to the corresponding positions identified in the LLSS dataset in order to provide an assessment of target location accuracies. Divers also reported that visibility was less than 1 ft at the seafloor following the storm, thus indicating that the LLSS would not produce any further imagery of the bottom of this field effort.

During the Year 2 survey, a transmissometer was used to evaluate water clarity at potential survey locations prior to deployment of the LLSS in an attempt to quantify and/or limit the impact of turbid conditions. The target string was deployed at a location at which transmissometer data indicated relatively clear water (corrected signal counts >3000; beam attenuation coefficient <1.115 m-1) within 1 m above the bottom. Moderate to good LLSS imagery was obtained for most targets; individual shapes and the optical resolution chart could be clearly identified and marked in the GeoDAS software. These data were deemed to be of sufficient quantity and quality for evaluation with respect to the performance goals of the calibration element.

6.5 DATA COLLECTION

During the acquisition of the successful LLSS imagery (i.e., clear pictures of individual targets) described above, both vessel and ROTV positional information were ported to topside computers running HYPACK 2009a and GeoDAS software packages to acquire, log, and process the various sensor data, as well as all associated GAPS-generated positions, towfish attitude, and other metadata. The GeoDAS system was employed as the primary means for generating a helmsman display for steering the survey tracklines over each survey area. All LLSS and associated meta-data were logged in the OIC format by the GeoDAS software. GeoDAS also provided the means to view the LLSS imagery in real time and in post-survey playback. The EdgeTech side scan sonar data was logged using EdgeTech Discover software. Data from various sensors were integrated into the GeoDAS software package based on the schedule of metadata inputs.

6.6 VALIDATION

6.6.1 Proposed Methodology

Following the completion of the calibration element, validation testing was to be conducted at the same location to evaluate the functionality of the LLSS as a UXO detection tool. The same target string used in the calibration study was to be deployed with the same UXO simulators and dummy targets reconfigured in a new order determined by deliberate random design prior to the cruise and otherwise unknown to the LLSS survey team. The FOCUS and LLSS were then to make multiple passes over the target line to evaluate the ability of the LLSS to accurately detect the presence of targets (detection frequency) and discriminate the UXO simulators from dummy objects (discrimination success).

6.6.2 Actual Accomplishment

During the Year 2 survey, the target string was deployed multiple times in Boat Lanes 7-10 over a 4-day field effort with the targets arranged in random orders for validation testing. These “blind” target arrangements were determined by the deck team selecting one of 40 preprinted validation sheets at random from the field binder and attaching the targets to the main line in the indicated order as predetermined by a random number generator. This sheet was not transferred to the data acquisition team until after final “blind” target identifications were made in post-processing. IXSEA transponder beacons were also attached to the beginning and end of the line at the anchor chain and clump, respectively, to provide precise positions for these points using

the GAPS navigation. Transponder beacons attached directly to the target string replaced the act of divers swimming the beacons to specific targets that was employed during the calibration element.

Turbidity conditions were again found to impede LLSS image quality during the validation testing. However, a suitable area was eventually located using the transmissometer data and four successful passes were made over a validation target string. A review of the LLSS data with the GeoDAS software indicated that high resolution images of the individual targets were clearly evident along portions of the string over hard bottom, and a reduction in image clarity occurred during the transition between hard bottom and muddy bottom; this transition was confirmed in the concurrent side scan data. An additional survey of this validation string was made with the FOCUS vehicle at a high altitude (~7 m) to assess the upper limit at which LLSS data could be obtained in these water conditions. Though vessel time limitations required that survey operations be ended following this activity, the collected data were deemed sufficient to conduct the proposed analyses and compare results against the established performance objectives.

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7.0 DATA ANALYSIS AND PRODUCTS

In terms of overall analysis of the LLSS technology, three main parameters were selected on which to base the performance evaluation: (1) image quality, (2) target morphometry, and (3) target positioning. Image quality refers to the relative success of the LLSS and various software applications to produce images that allow for the shape, condition, and specific identity of various targets to be clearly identified. Target morphometry refers to the ability of the LLSS to accurately determine the dimensions (i.e., length, width) of targets identified in the digital images compared to the known dimensions of these same targets. Finally, target positioning refers to the ability of the LLSS to accurately determine the specific horizontal position (i.e., latitude, longitude, northing, easting) of targets identified in the digital images compared to the known positions as determined from GPS beacons (accuracy), as well as to show good repeatability in these positions during target reacquisition over multiple passes (precision). In addition to the data analysis objectives determined during the planning phase, water clarity was also identified during the demonstration surveys as an integral parameter affecting LLSS performance. Therefore the transmissometer data collected during the validation element were included in the assessment process and used to quantify the level of water clarity needed to produce successful LLSS images.

7.1 PREPROCESSING

During the data acquisition process, all LLSS image, geolocation, and sensor data were merged simultaneously using the GeoDAS software. Corrections for sensor layback, altitude above the seafloor, and aperture opening were made through settings input into the GeoDAS display prior to the start of data acquisition. Following acquisition, all LLSS files were named with a unique moniker consisting of specific identification codes for survey year (ESTCP1=Year 1, ESTCP2=Year 2), general area (SDB=San Diego Bay), specific area (BL=Boat Lanes) and target order (01=first target arrangement for that survey, incremented sequentially independent of calibration versus validation strings). Multiple passes over the same target string were indicated with a letter (A=Pass 1). At the end of each survey day, all LLSS data collected that day were reviewed (i.e., played back) with the GeoDAS software to develop a general estimate of the number of targets successfully imaged. These files were then saved to a dedicated portable hard drive (in addition to the main data acquisition computer).

7.2 TARGET SELECTION FOR DETECTION

The LLSS image data collected during the demonstration surveys consisted of multiple passes over a single calibration string in Year 1 as well as calibration and validation strings in Year 2. No specific “dig list” was produced for this LLSS demonstration because all targets were placed by the project team at known locations, thus random discovery of objects in the environment to be targeted for reacquisition was not relevant.

7.2.1 Image Identification Process

The GeoDAS Target View dialog box was used for initial target selection and characterization. This software feature allowed targets to be marked, measured, and classified, which facilitated

the down selection of target images and associated size and positioning information for further analysis.

7.2.2 Image Acquisition Summary

The Year 1 effort successfully imaged 21 out of the 22 potential targets during each of two passes over the calibration string. On the first pass, quality laser images were collected for all nine simulated UXO objects, 10 out of 11 dummy objects, the eye chart, and the Danforth anchor. The second pass over the calibration string proceeded in the opposite direction and captured quality laser images for all nine simulated UXO objects, all 11 dummy objects, and the eye chart. Targets were readily identifiable upon survey playback. Example screen shots from the GeoDAS waterfall for each target in the order of acquisition during Pass 1 are found in Figure 7. It should be noted that these images represent raw data collected in real time and are not presented at full resolution nor are they geometrically rectified.

The Year 2 survey collected LLSS images from seven passes over two separate calibration strings and six passes over two separate validation strings. In some cases, the specific nature of the objects was unidentifiable (i.e., just a general outline was visible) due to reduced water quality, thus preventing quantification of the exact number of UXO simulators versus the number of dummy objects.

Targets in the Year 2 validation dataset were identified using CleanSweep2 software rather than just the GeoDAS acquisition waterfall display, as was done previously for the calibration element. This additional procedure was adopted in order to evaluate the quantitative and qualitative advantages of using CleanSweep2 as the initial image identification tool. Example Year 2 target images obtained from the CleanSweep2 software are provided in Figure 8.

7.2.3 Image Post-Processing

Year 2 target images from the GeoDAS acquisition display were post-processed using CleanSweep2 as well as the SAIC Microsoft DOS-based software tool. According to the side-by-side comparisons shown in Figure 9, the morphometrics were relatively equal between CleanSweep2 and GeoDAS for all targets. Based entirely on objective observation, CleanSweep2 appeared to produce higher resolution for images 1-4, but GeoDAS appeared to produce higher resolution for images 5-8. Overall, the SAIC software produced image resolution comparable to both the GeoDAS and CleanSweep2 displays. However, the SAIC software does not georectify the image. This effect would not limit the discrimination of UXO versus similar looking dummy objects, but it would limit the positive identification of the specific type of UXO observed if dimensionality was the critical diagnostic parameter.

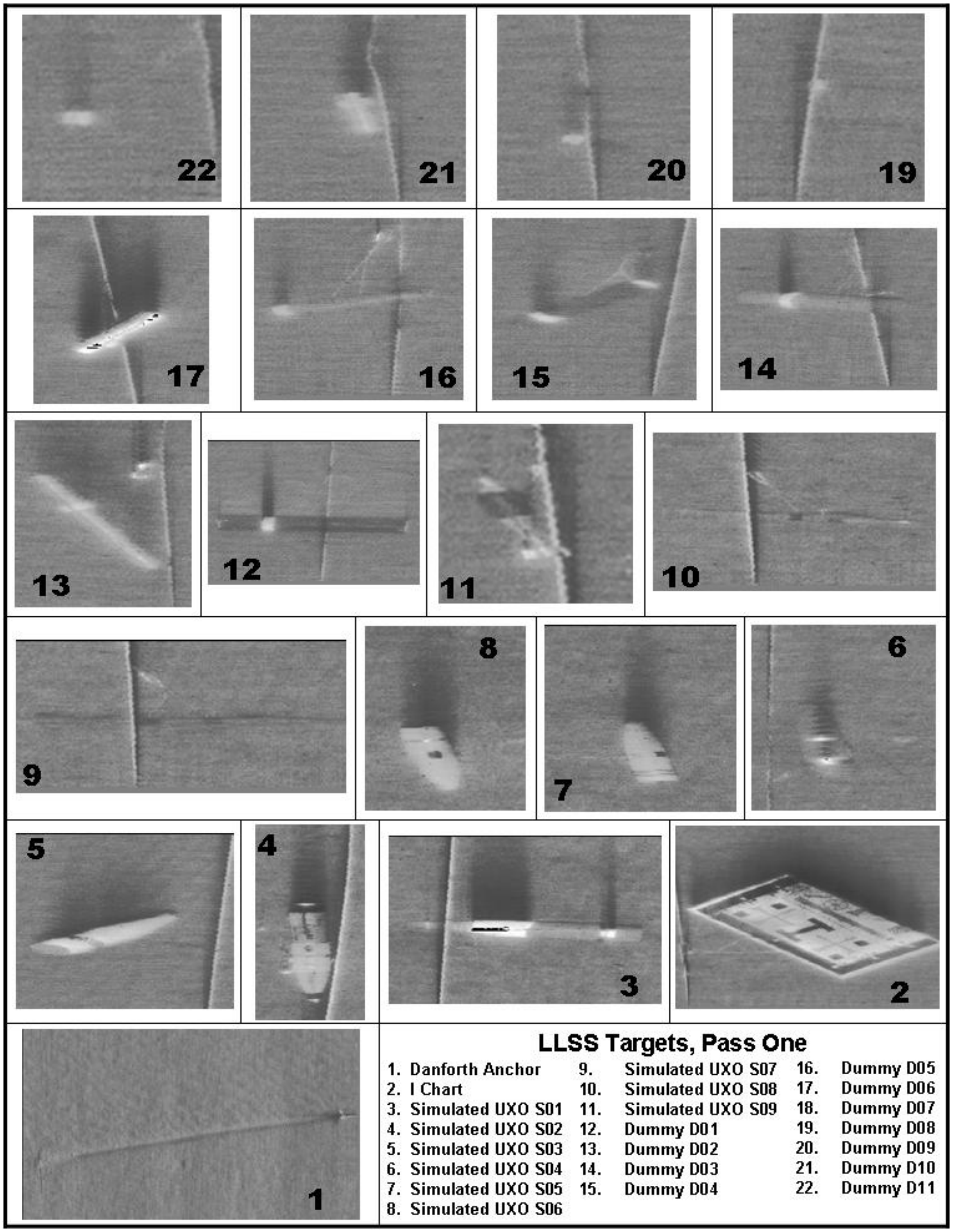

Figure 7. Screen shots from the GeoDAS waterfall for targets along the calibration string imaged during Pass 1 of the Year 1 survey.

Note: The imagery in this figure is not presented at full resolution nor geometrically rectified.

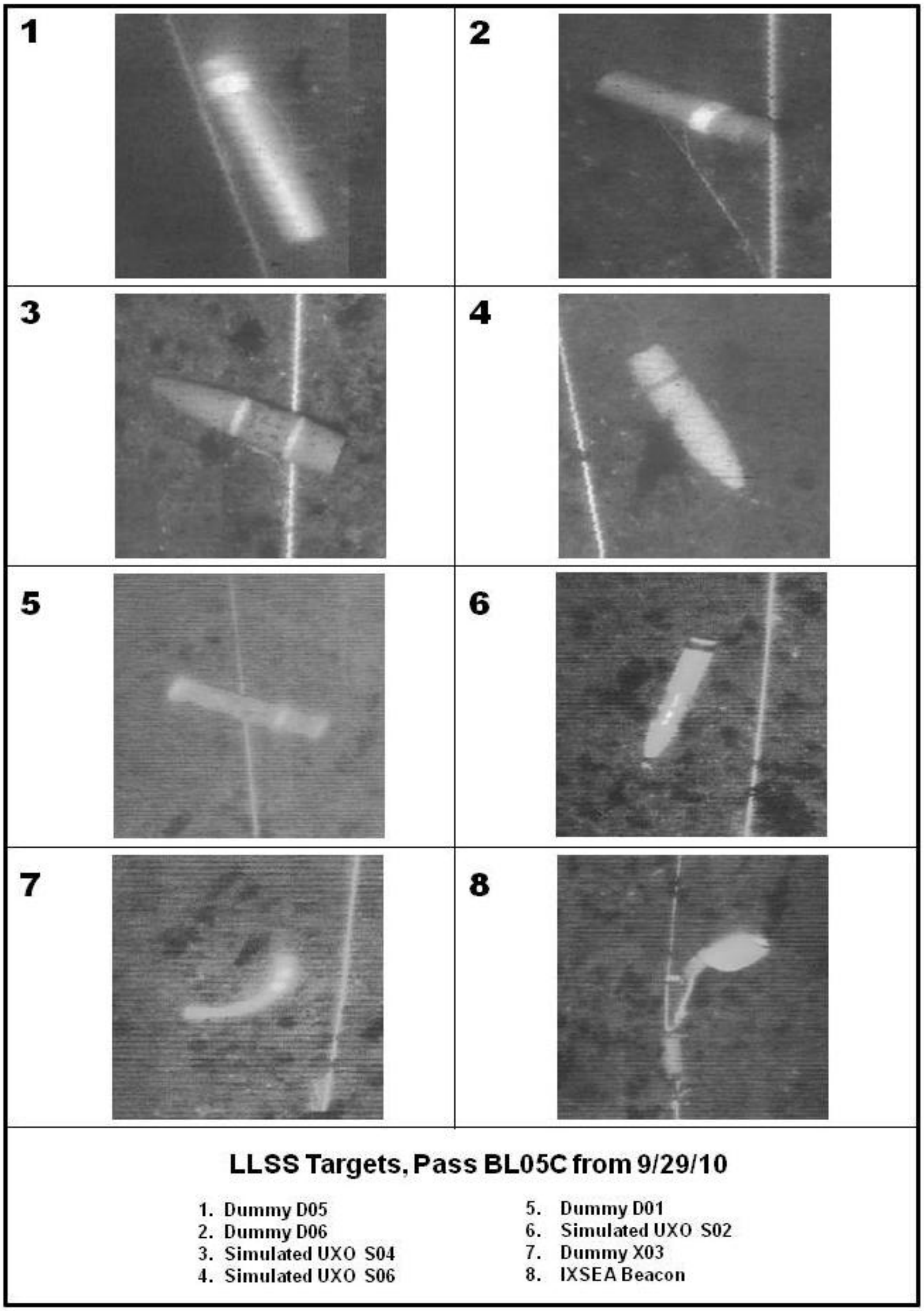

Figure 8. Screen shots from CleanSweep2 for targets along Validation Line 2 imaged during Pass BL05C of the Year 2 survey.

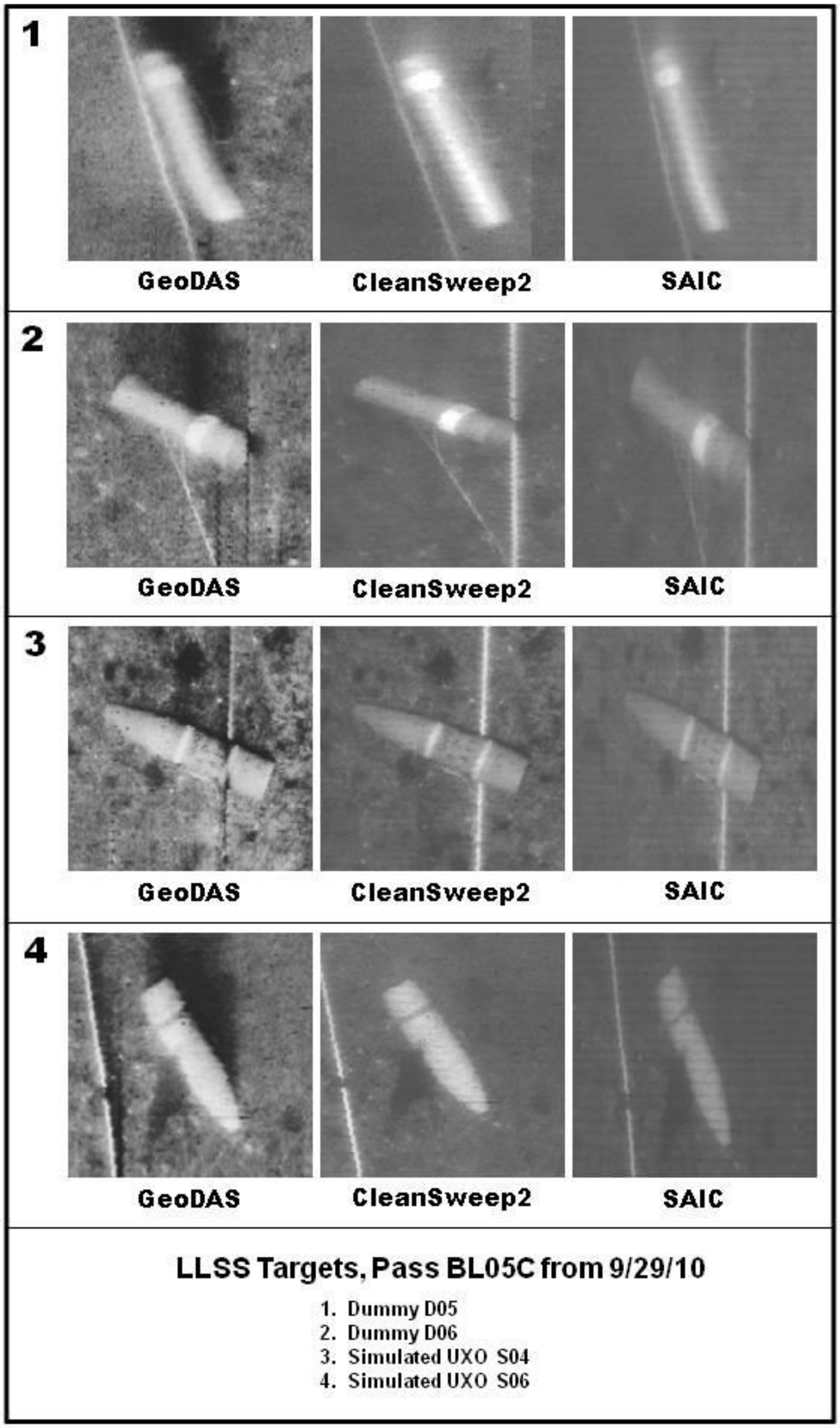

Figure 9. Comparison of the raw GeoDAS images and the post-processed CleanSweep2 and SAIC software images for all targets identified in Pass BL05C from Year 2.

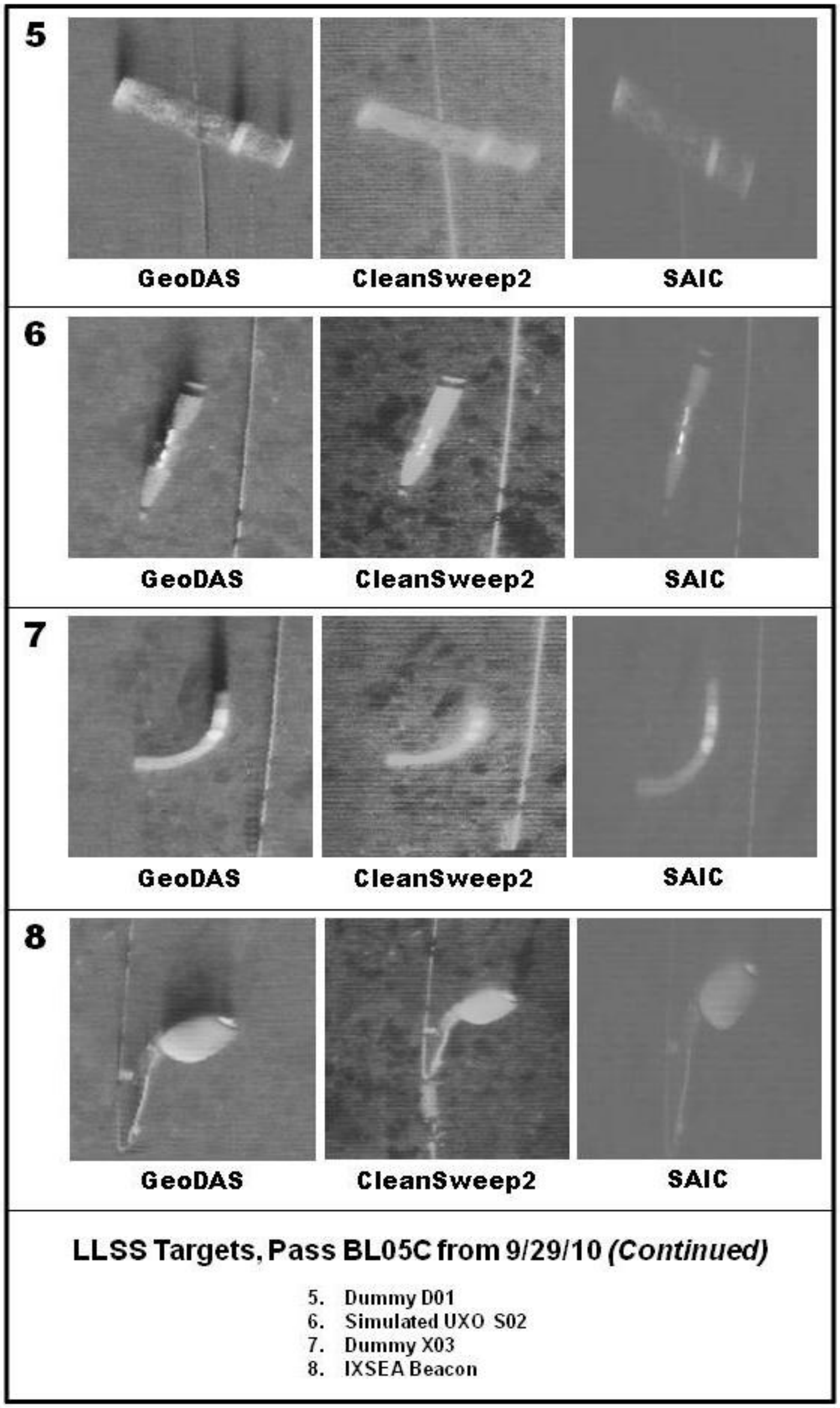

Figure 9. Comparison of the raw GeoDAS images and the post-processed CleanSweep2 and SAIC software images for all targets identified in Pass BL05C from Year 2 (continued).

7.2.4 Overall Image Quality

The images produced by the SAIC software were considered adequate representations of the targets. However, it is clear that additional processing with GeoDAS and/or CleanSweep2 may produce a more life-like image that in some situations could aid in the discrimination and otherwise improve decision making based on the specific type of UXO present. Such a situation may occur if live fire was used for certain munitions types while only inert simulators were used for other munitions types.

7.2.5 Altitude Effects on LLSS Performance

When both the low altitude LLSS results for Pass BL05C and the high altitude LLSS results for Pass BL05D are mosaiced at 6 cm resolution for the same portion of the target string, the swath width (i.e., lateral coverage by the sensor perpendicular to direction of travel) increases from 5.7 m to 8.8 m with the approximately 2 m increase in sensor altitude (Figure 10). Consequently, the survey coverage rate increases from 3.1 hectares per hour (ha/hr) to 4.8 ha/hr, an approximately 50% increase when using the higher altitude. In terms of image quality, the comparative mosaics indicate that the presence of targets and their generic properties (e.g., general shape, orientation) can be observed at both low and high altitude. However, image quality from the CleanSweep2 display was found to be vastly improved at the lower altitude.

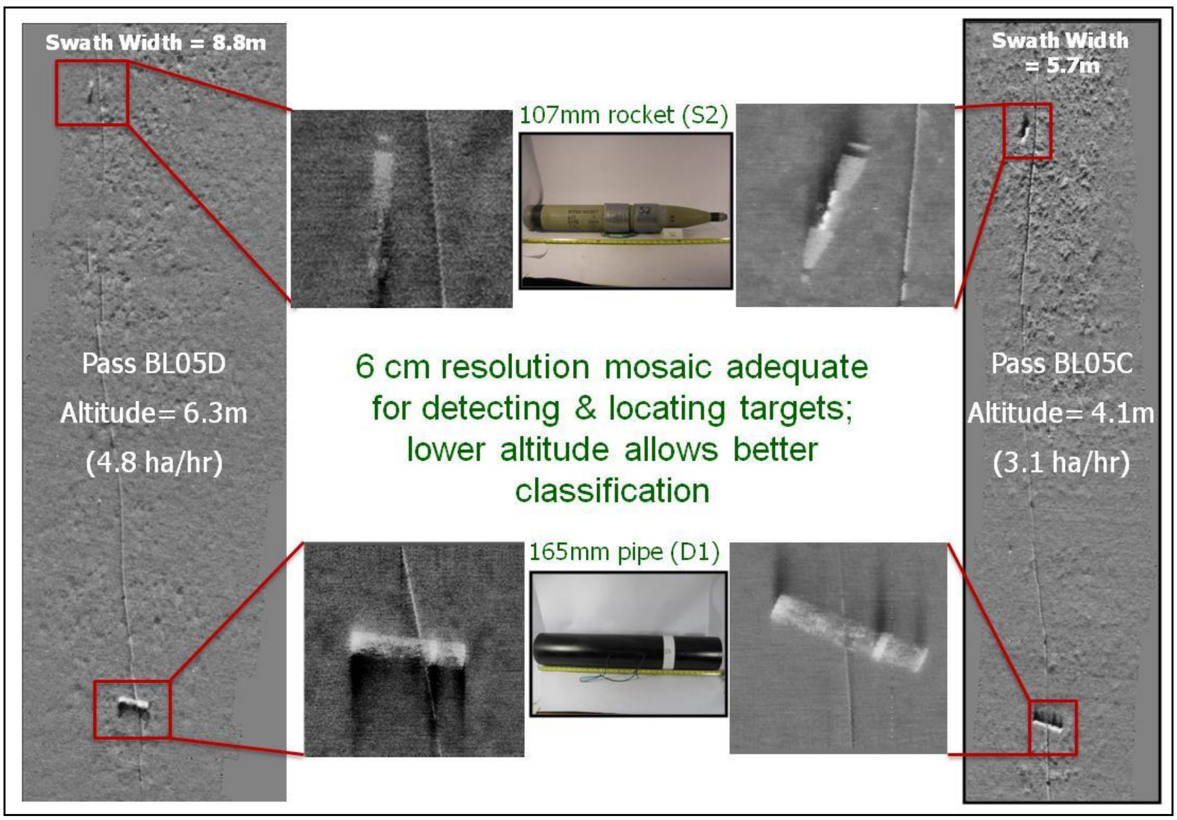

Figure 10. Comparison of LLSS target image and seafloor mosaic results for two passes over Validation Line 3 conducted at different sensor altitudes.

7.3 PARAMETER ESTIMATES

In terms of morphometry and positioning, post-survey data analysis involved the review of LLSS images collected during the most successful passes over calibration and validation target strings from both Year 1 and Year 2 and comparison of these results with known target characteristic and positioning information. In terms of water clarity requirements, transmissometer data collected during the Year 2 survey were correlated to the relative success of the LLSS in producing quality images at corresponding locations.

7.3.1 Target Morphometry

Of all the target strings surveyed during Year 2, BL05C (Validation Line 3) was selected for target measurement analysis as this pass produced clear images that allowed for definitive length and width measurements that could be compared to the corresponding actual dimensions for each target. When grouped together, the overall length and width LLSS measurements showed good correlation to actual measurements (slope=1.05; r^2=0.97) (Figure 11), with image measurements being on average 5% larger than actual.

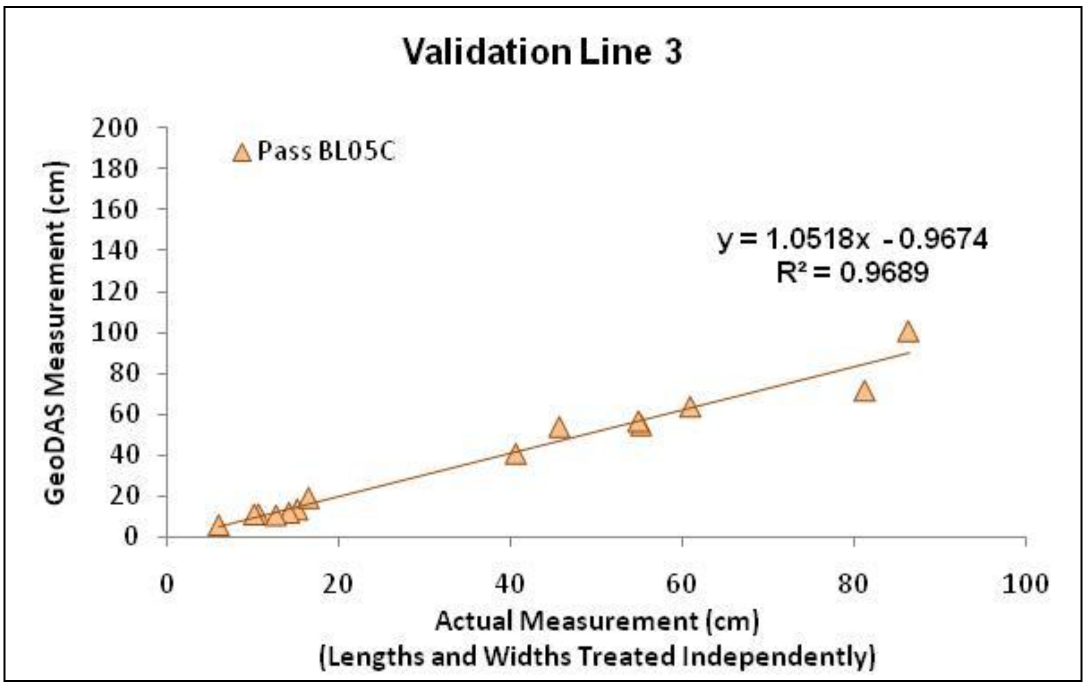

Figure 11. GeoDAS measurements of known targets calculated for Pass BL05C during the Year 2 validation effort.

7.3.2 Target Positioning

When evaluating the positioning capabilities of the LLSS, both accuracy and precision were considered in the overall assessment. In this case, accuracy refers to the position of the targets identified in the LLSS images compared to the known positions of the same targets as determined from GPS beacons placed on the targets themselves. In contrast, precision refers to

repeatability of multiple positions for the same targets determined from multiple passes over the same target string.

7.3.2.1 <u>Precision</u>

To evaluate LLSS precision, geodetic positions for each LLSS target identified during four passes over Validation Line 3 were obtained from the CleanSweep2 playback. These positions should theoretically be identical assuming that the targets did not move between passes. A circular error plot was developed to concurrently display the relative corrected positions of each target from all four LLSS passes over the target string in a standard x,y coordinate plane (Figure 12). Based on the results for Validation Line 3, 50% of repeated LLSS-detected target positions would be expected to fall within 1.65 m of the originally measured position for any target over multiple passes during a given LLSS survey. Furthermore, 65% of repeated LLSS-detected positions would be expected to fall within 1.98 m and 95% of repeated LLSS positions would be expected to fall within 3.96 m. Therefore the minimum level of precision for the LLSS (i.e., maximum linear deviation for repeated positions of the same target) is concluded to be no greater than 4 m (at a 95% confidence level). These precision results are consistent with the difference in target positions of 3.9 +/- 2.0 m measured for the two passes in Year 1.

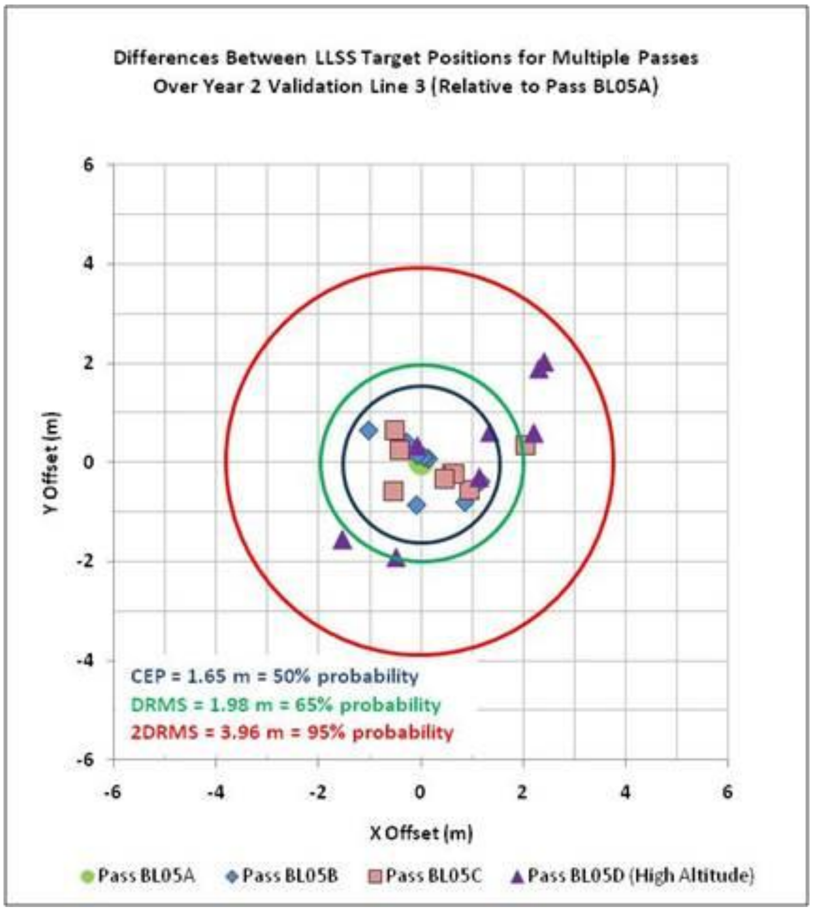

Figure 12. Circular error probability plot showing corrected target positions from three passes over Year 2 Validation Line 3 relative to corrected target positions from Pass BL05A. Circular error statistics are also shown.

7.3.2.2 Accuracy

For the accuracy evaluation, "true" horizontal positions were collected for the clump weight on one end of Validation Line 3 by attaching an IXSEA mobile transponder beacon to the weight and obtaining the position of that beacon from the GAPS system independent of the LLSS. This weight/beacon combination was then successfully imaged on two LLSS passes over the target string (BL05A and BL05C) and the resulting positions were obtained from both the CleanSweep2 and GeoDAS playbacks. As shown in Figure 13, the accuracy was relatively consistent for each software application over both passes, but overall CleanSweep2 produced better positional accuracy than GeoDAS (shapes clustered closer to the graphical origin). Although both software applications receive the same navigation data input, the different image filters applied by CleanSweep2 make better use of this data for georectification, thus producing slightly more accurate positioning. CleanSweep2 produced an accuracy of approximately 2 m while GeoDAS produced an accuracy of approximately 3 m. These Year 2 accuracy values showed a substantial improvement over the highly uncertain diver-determined data from Year 1.

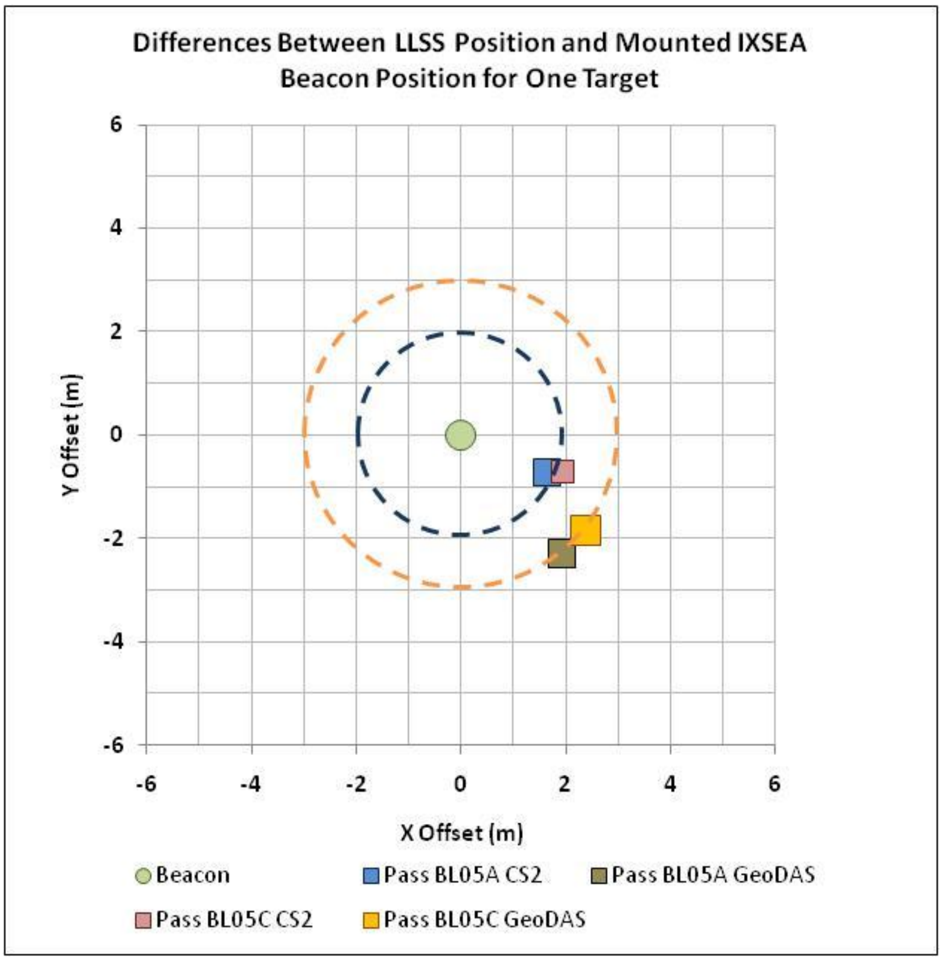

Figure 13. Corrected LLSS positions for one target on Year 2 Validation Line 3 as determined over multiple passes with both CleanSweep2 and GeoDAS software relative to the true position as determined with an IXSEA beacon.

7.3.3 Water Clarity Requirements

Since the LLSS is essentially an optical instrument based on the ability of a laser light source to scan the seafloor, water clarity was identified as an integral environmental factor affecting LLSS image quality during both the Year 1 and Year 2 demonstration surveys. In order to quantify the effects of water clarity (i.e., transmissivity) on LLSS performance, the transmissometer data collected during the Year 2 survey was used to calculate a minimum beam attenuation coefficient (a common transmissivity measurement) at which the LLSS would be expected to produce successful images during future operations. Based on this limited comparative dataset, the minimum conclusions were reached that the LLSS will produce high quality images in bottom water with a beam attenuation coefficient <1.115 m^{-1} and will not produce successful images in bottom water with a beam attenuation coefficient >2.453 m^{-1}. Waters with beam attenuation coefficients between these values will produce LLSS images of variable quality, with values <1.179 m^{-1} having a greater potential for success. Additional data would be needed to narrow the range for predicted success.

7.4 TARGET CLASSIFICATION AND TRAINING

Target classification was addressed during the Year 2 survey with completion of the validation element of the project, during which validation strings were deployed with target orders unknown to the LLSS data acquisition and analysis team. Here, the classification (i.e., identification) of these targets was dependent solely on the LLSS imagery.

7.4.1 Blind Testing Methodology

The LLSS data collected for each validation string featuring a blind arrangement of targets was ultimately used to populate a preprinted log that served as a de facto scorecard for blind testing performance. Tier I classification involved determining the location of each target position (P01, P02, etc.) along the validation string in the software playback (CleanSweep2 or GeoDAS) based the presence of a target in the LLSS image. If a target was present, both visual discrimination and LLSS measurements were used to determine whether the target was a UXO simulator or dummy object (regardless of the specific target ID). Tier II classification then involved using these same processes to determine which specific individual target was present in each image. These steps were accomplished without knowledge of the true target configuration, which was still maintained only by the SPAWAR project manager (PM).

7.4.2 Blind Testing Results

Although three different validation strings were deployed during the Year 2 survey, successful LLSS images fit for data analysis were collected only for Validation Line 3 (Line ID: BL05). The final scorecard prepared for Validation Line 3 showing both Tier I and Tier II classification results and percent success is provided in Figure 14. These blind testing results show that the general classification (UXO simulator versus dummy object) was correctly identified for 8 of 9 targets surveyed and the specific target ID was correctly identified for 7 of 9 targets surveyed. These results translate to a Tier I success probability of 89% and a Tier II success probability of 78% based on limited data from one validation string.

Node	Tier 1: General classification of targets				Tier 2 Specific ID	True Target ID	Tier 1 Score	Tier 2 Score
P12	Simulated UXO		Dummy Object	X	D5	D5	1	1
P13	Simulated UXO		Dummy Object	X	D6	D6	1	1
P14	Simulated UXO	X	Dummy Object		S4	S4	1	1
P15	Simulated UXO	X	Dummy Object		S6	S6	1	1
P16	Simulated UXO	X	Dummy Object		Uknown	S7	1	0
P17	Simulated UXO		Dummy Object		Not Observed	D11	0	0
P18	Simulated UXO		Dummy Object	X	D1	D1	1	1
P19	Simulated UXO	X	Dummy Object		S2	S2	1	1
P20	Simulated UXO		Dummy Object	X	X3	X3	1	1
Percent Classification Success		=	Total Score / Total # Targets	X	100	Total Score:	8	7
							Tier 1	**Tier 2**
Percent Classification Success		=	9	X	100 =	**% Classification Success**	89	78

Figure 14. Target classification results for Year 2 Validation Line 3 showing both Tier I and Tier II success.

7.5 DATA PRODUCTS

The primary data products for the LLSS demonstration are the figures and tables included in the Final Report. Survey activities were also used to develop secondary data products such as refined methodologies for system configuration, pre-deployment dry testing and sensor deployment that would be integral to the success of future UXO surveys. The results of the Year 1 demonstration were also used to identify a flaw in the GeoDAS software package which facilitated development of a software patch and alternate processing techniques that resulted in greatly improved image quality for this and future LLSS operations.

8.0 PERFORMANCE ASSESSMENT

The LLSS demonstration as conducted yielded enough field data to evaluate all of the performance objectives established in Section 4.0 to varying degrees, but the adverse weather and water quality conditions experienced during both the Year 1 and Year 2 surveys greatly limited the final data products compared to what was originally proposed in the test plan. The final results for all performance objectives developed from both the Year 1 and Year 2 data are presented in Table 2.

Table 2. Summary of performance results for the LLSS demonstration.

Performance Objective	Success Criteria	Survey	Results	Criteria Met?
Quantitative Performance Objectives				
Depth station keeping	+/-1 m over 50% survey length	Year 1	• Avg. altitude of 3.7±0.3 m for Pass 1 with target altitude of 3-4 m • Avg. altitude of 3.3±0.3 m for Pass 2 with target altitude of 3-4 m	Yes
		Year 2	• Avg. altitude of 3.7±0.8 m for conventional passes with target altitude of 3-4 m • Avg. altitude of 7.0±0.5 m for high altitude pass with target altitude of 7-8 m	
Line station keeping	+/-3 m across track	Year 1	• <3 m of the target survey line for 100% of both passes • <2.1 m of the target survey line for 99% of both passes	Yes
Data preprocessing and creation of mapped data files	<1 hour	Year 1	• Avg. 23 minutes per 500 m (1640 ft) segment of LLSS imagery without georectification	Yes
		Year 2	• Avg. 45 minutes per 500 m (1640 ft) swath of LLSS imagery with georectification	
Target analysis and dig list time	<3 hours	Year 1	• 2 hours per 500 m (1640 ft) swath of LLSS imagery from the end of data pre-processing using GeoDAS	Yes
		Year 2	• 2.5 hours per 500 m (1640 ft) swath of LLSS imagery from the end of data pre-processing using CleanSweep2	
Survey production rates	>42,000 m^2/hour	Year 1	• Avg. rate of 27,972±2268 m^2/hour for Pass 1 with target altitude of 3-4 m • Avg. rate of 24,948±2268 m^2/hour for Pass 2 with target altitude of 3-4 m	Initial criteria for 5 m altitude N/A No for expected low altitude rate (30K m^2/hr) Yes for expected high altitude rate (53K m^2/hr)
		Year 2	• Avg. rate of 27,114±3390 m^2/hour for 12 conventional passes with target altitude of 3-4 m • Avg. rate of 52,705 m^2/hour for high altitude pass with target altitude of 7-8 m	
Probability of surrogate target detection	>90%	Year 2	• 89% of total targets surveyed	No, but sample size limited to 9 targets

Table 2. Summary of performance results for the LLSS demonstration (continued).

Performance Objective	Success Criteria	Survey	Results	Criteria Met?
Probability of false alarm	<10%	Year 2	• 0% of total dummy objects surveyed	Yes
Probability of false negative	<10%	Year 2	• 0% of total UXO simulators surveyed	Yes
Target location accuracies	+/-50 cm	Year 2	• 2 m between the LLSS position and known position for one target when using CleanSweep2 software; 3 m when using GeoDAS software	No, but 2 m accuracy coupled with clear LLSS image deemed acceptable for reacquisition
UXO parameter estimates	+/-5 cm	Year 2	• Avg. 3.4+/-4.3 cm of the actual target dimension for all lengths and widths combined when using the GeoDAS display	Yes
Survey coverage/missed areas	<5%	Year 1	• 95% of the total survey area (i.e., total targets placed) covered on Pass 1; 5% of the survey area missed (i.e., requiring re-mapping) • 100% of the total survey area (i.e., total targets placed) covered on Pass 2	Yes
Qualitative Performance Objectives				
Ease of use	Relative ease	Year 1 & 2	• System is easy to mobilize and demobilize given proper planning to ensure the necessary equipment (e.g., cranes, welders, cables, etc.) is present. • LLSS/FOCUS is easy to deploy and recover in a variety of sea states. • Ability to produce high quality LLSS images is highly dependent on water clarity and level of ambient light at the time of data collection.	Yes
System reliability	<1%	Year 1 & 2	• 1 entire day of planned operations lost due to the need for required LLSS equipment repairs	No, but down time coincided with unforeseen site access delays so time lost did not impact final survey time
Maintenance	<10 min	Year 1 & 2	• 1-2 minutes to visually check FOCUS for debris (e.g., seaweed) and re-tape breakaway line mounts for safe launch and recovery on the following deployment. • <10 minutes to properly align GAPS/PHINS INS with magnetic north at the beginning of each survey day. • No extensive cleaning, decontamination or calibration steps between deployments	Yes

9.0 COST ASSESSMENT

This section is intended to provide sufficient cost information such that a professional involved in the field could reasonably estimate costs for implementation of the LLSS technology at a given site. In addition, this section provides a discussion of the cost benefit of the LLSS technology in comparison to other marine UXO survey approaches.

9.1 COST MODEL

The cost model for this survey is based on potential expenses for the site preparation, mobilization, survey operation, demobilization, and survey product tasks. As per the cost analysis guidance established in the Year 2 Demonstration Plan, the cost model also includes a breakdown of the approximate capital costs for developing and fielding the equipment. The complete cost breakdown for conducting an LLSS survey is shown in Table 3. The dollar amounts presented for each line item therein are based on five active field survey days off the coast of San Diego, with one additional day each for mobilization and demobilization.

Table 3. Cost breakdown structure for the Year 2 LLSS demonstration conducted off the coast of San Diego.

Cost Element	Data Tracked During Demonstration	Estimated Cost ($K)
Capital costs	Capital equipment purchase	997.0
	Ancillary equipment purchase	30.1
	Software purchase (GeoDAS)	10.0
	Equipment development (in-house service center)	22.0
	Equipment integration	2.5
	Equipment shakedown and testing	3.5
Site preparation costs	Evaluation trip/meetings	N/A
	UXO simulator purchase	2.5
	Design/construct target strings	4.4
	Develop HASP	5.0
	Develop/approve demonstration plan	17.0
Mobilization costs	Personnel travel (airfare, lodging, vehicle)	6.0
	Equipment prep and loading (at SAIC warehouse)	4.4
	Equipment transport (truck and forklift rental)	0.9
	Equipment unloading (dockside)	13.0
	Equipment setup (crane and welding)	3.5
Survey operation costs	**Item Costs**	
	Generator fuel	1.0
	Data storage (external hard drive)	0.3
	Software rental (CleanSweep2)	3.0
	Equipment spares used	N/A
	Miscellaneous logistics (shipping, expendables)	0.8
	Daily Costs	
	Daily labor support costs (6 workers)	13.0
	GAPS/PHINS rental and engineering support (1 worker)	2.9
	Survey vessel	8.0
	Unit Costs (3 Survey Days)	
	Survey cost/hectare (search and recovery)	4.5
	Survey cost/hectare (wide area assessment)	0.65
	Cost/ survey hour (search and recovery)	22.1
	Cost/ survey hour (wide area assessment)	3.2

Table 3. Cost breakdown structure for the Year 2 LLSS demonstration conducted off the coast of San Diego (continued).

Cost Element	Data Tracked During Demonstration	Estimated Cost ($K)
Demobilization costs	Equipment breakdown (crane and welding)	3.5
	Equipment prep and loading (dockside)	13.0
	Equipment transport (truck and forklift rental)	0.9
	Equipment unloading (at SAIC warehouse)	4.4
	Personnel travel (airfare, lodging, vehicle)	6.0
Survey products	Data processing	17.7
	Target analysis	3.9
	Survey graphic products	3.9
	Survey report	0.5

9.1.1 Capital Costs

The capital costs for the development and fielding of the LLSS equipment include approximations for capital and ancillary equipment purchases, software purchases, engineering design and development costs (i.e., in-house service center), component and system integration costs, and shakedown and testing costs. They do not include costs for project management, project reporting, maintaining the support facility, or other incidentals such as the purchase of specialized equipment to support the development, site license and permit fees, etc.

The capital, ancillary, and software purchase costs listed on Table 3 represent the declared asset values for these items within the SAIC service center. Capital equipment includes all specific hardware components needed to complete an LLSS survey in the manner described in this report; this equipment includes everything associated with the SM-2000 LLSS itself (sensor, console, electronics bottle, spares), the FOCUS vehicle (Kongsberg altimeter, control console, fiber optics bottle, sound velocity profiler (SVP) sensor, frame, and chassis), the FOCUS winch (cable drum, cable counter, slip ring, tow cable), and the supporting geophysical sensors (EdgeTech side scan sonar/sub bottom profiler, EdgeTech console). In contrast, ancillary equipment includes the diesel generator needed to power the FOCUS winch; this is an SAIC owned item but could theoretically be replaced with any generator of similar size or shipboard power if the survey vessel can provide sufficient output. The software value represents the cost for purchasing the proprietary GeoDAS platform from the single sole source provider OIC that is needed at minimum to operate the LLSS.

It should be noted that the overall LLSS as configured for this demonstrations represents a prototype system developed by SAIC, and a similar system cannot simply be purchased off the shelf by an outside contractor. In order to create a duplicate system, the individual components would have to be purchased separately from the manufacturer and then assembled. Although the capital equipment purchase costs for this system are listed at $997,000, this value reflects the original cost of the system when constructed in the 1990s. It is estimated that a duplicate system could be constructed from more modern hardware for less cost.

9.1.2 Site Preparation Costs

Site preparation costs for LLSS operations conducted in the manner described in this report are relatively minor compared to other UXO survey approaches. In contrast to geophysical-based

(i.e., magnetometer) technologies such as the marine towed array (MTA) (SAIC, 2008), the LLSS is an optical-based technology and thus does not require substantial effort to be spent on a geophysical systems verification prove-out task or establishment of fixed calibration and test sites featuring magnetic targets placed by divers or otherwise deployed by subcontractors prior to the survey. Site preparation for the LLSS demonstration does, however, involve purchase of the materials (e.g., line, anchors, floats, shackles) needed to construct the target string as well as the time needed for the survey personnel to prepare and configure these items shoreside prior to the survey. Also required is the purchase of the targets themselves; because the official UXO simulators are only available directly from a U.S. Army supplier, the cost for these items is relatively high ($2500 for the set) compared to common inert items (e.g., pipes). The target string expenses represent a one-time cost, however, since these items can be reused for multiple demonstrations (assuming they are not lost during deployment/recovery operations).

Furthermore, because LLSS operations are strictly visual and do not directly support any target investigation or recovery operations (aside from topside recovery of the target strings for reuse), the demonstration is considered nonintrusive, which significantly reduces the requirements for development of a detailed HASP involving UXO or MEC operations; certified UXO specialists are not obligatory as part of the survey team nor is a separate ESS required. Similarly, deployment and recovery of target strings from the survey vessel eliminates the need for diver support as well as an associated dive plan and added health and safety requirements. Instead, the HASP for typical operations of towed sensors on a large offshore vessel and an appropriate laser safety plan are the only documents required to address the typical hazards associated with LLSS operations. The Demonstration Plans produced for both the Year 1 and Year 2 surveys are expected to be applicable almost in their entirety to any future demonstrations of this technology, which would significantly reduce the effort needed for the planning stage.

9.1.3 Mobilization Costs

The mobilization costs for the LLSS are made up of the preparation, transport, and setup costs for the system as well as travel costs for the specialized personnel required to operate the technology. The values presented for mobilization in Table 3 are based on transportation of the system from the SAIC Marine Operations facility on Ponderosa Avenue in San Diego to the SPAWAR dock on San Diego Bay, as well as travel for the SAIC employees participating in the demonstration; of the six total employees, two were local to San Diego and thus incurred no travel costs, but the remaining four were required to travel to San Diego from Newport, RI. Because the overall LLSS contains several extremely large pieces of equipment weighing several thousand pounds (e.g., FOCUS vehicle, generator, hydraulic winch, piloting console, navigation pole mount, several cases of miscellaneous hardware, etc.), rentals of both a large forklift and a flatbed truck were needed to complete the transport task. The loading (conducted at the SAIC Marine Operations facility) and the unloading (conducted at the SPAWAR dock) tasks each encompassed one day and were conducted by the survey personnel as well as additional SAIC employees from the local facility as needed.

Due to the overall size of the LLSS components (especially the generator and winch), a shoreside 70-ton crane with a long-boom was required in addition to the shipboard crane to safely load the system from the dock onto the survey vessel. Furthermore, welders were needed to attach mounts for the generator, winch, and navigation pole directly to the deck of the survey vessel to allow for the structural tie-down support required for safe operation on a rolling ship. Both the

shoreside crane and welding services were provided by local subcontractors, the costs of which are included in the equipment setup task.

In general, mobilization costs for the LLSS demonstration were relatively low due to the fact that the surveys were conducted in San Diego, thus limiting equipment transport to approximately 15 miles and eliminating travel costs for a portion of the personnel. Should future LLSS demonstrations be conducted at remote sites, equipment mobilization costs would be expected to rise substantially as the large equipment would have to be shipped either via flatbed truck or barge to the destination. However, personnel mobilization costs would be expected to decrease as fewer technicians would be required for typical LLSS operations than were needed for the demonstration.

9.1.4 Survey Costs

The survey operation costs presented in Table 3 are broken down into both item costs and daily costs and are also shown in terms of unit costs per coverage area and survey hour. These costs are all based on the Year 2 demonstration, which took place over a period of three active survey days not including the mobilization and demobilization days, the one wet test day in San Diego Bay, or the one day spent on the dock waiting for security clearance, during which time equipment maintenance was performed.

9.1.4.1 Item Costs

The individual lump sum item costs for the Year 2 survey included diesel fuel for the generator (needed to operate the FOCUS winch), purchase of a dedicated external hard drive for data management (needed for daily data backup and transport), rental of the proprietary CleanSweep2 software (minimum one week block), and costs for miscellaneous logistics (e.g., shipping of toolboxes and health and safety equipment, purchase of expendable items such as small tools and paper towels, etc.). CleanSweep2 may not be required depending on the scope of work to analyze images for future production surveys; a combination of GeoDAS (for acquisition) and SAIC software (for post-processing) could be used instead.

The repair and maintenance costs for the LLSS specific to this demonstration have not been calculated because the system has not yet been remobilized to support another UXO survey. Thus the cost for equipment spares is not applicable to this assessment. Instead, the predicted routine maintenance and repair costs typically associated with any LLSS survey are included in the equipment development (i.e., in-house service center) section of the capital costs.

9.1.4.2 Daily Costs

The survey vessel R/V *Acoustic Explorer* was provided directly by the Navy at a daily rate determined by a pre-existing long-term service contract between the vessel owner and SPAWAR.

The Year 2 demonstration was performed by six SAIC personnel not including the vessel crew or the SPAWAR PM. Each member of the SAIC crew possessed specialized skills critical to the demonstration and was responsible for filling a unique role during active survey operations; these roles included PM, FOCUS preparation, FOCUS pilot, LLSS data acquisition (software

operator), side scan data acquisition (software operator) and target manager. All survey personnel are “on the clock” at all times when on the survey vessel. The target manager remained on deck for most of the survey and, along with the SPAWAR PM, was responsible for executing the blind testing target arrangements unknown to the rest of the data acquisition team. All six members of the SAIC crew would be required to maximize efficiency of future LLSS demonstrations, but similar surveys could reasonably be completed with four or five-member survey teams.

The GAPS/PHINS navigation system was rented for the survey based on daily rates for the individual components as determined by the IXSEA company. These rates included separate amounts for the individual GAPS and PHINS units as well as three transponder/responder beacons. Also included in the GAPS/PHINS daily costs were travel, per diem and compensation rates for one IXSEA engineer who also participated in the Year 2 survey. The role of this individual was to set up and operate the IXSEA equipment during active survey days as well as to provide any necessary onsite engineering or technical support throughout the operation. Similar onsite support may not be integral to all LLSS demonstrations, but it is greatly beneficial if the survey crew is not familiar with operation of the GAPS/PHINS system, as well as to ensure that any subsea navigation problems are addressed in a time efficient manner.

9.1.4.3 Unit Costs

Similar to both the item and daily costs described above, the unit costs for the LLSS are based on the Year 2 demonstration only. The survey cost/hectare (search and recovery) value provided in Table 3 ($4500) was calculated as the sum of the item and daily costs for three survey days ($76,800) divided by the total area covered by all the individual passes conducted during those three days (17 ha); this area did not include vessel turnaround time between each pass during which data was not logged. As LLSS coverage is ultimately dependent on FOCUS altitude and tow speed, the cost/hectare assumes a conventional low altitude swath of 4 m and tow speed of 1.5 meters per second (m/s).

It is important to note, however, that this unit cost reflects the actual results of the Year 2 survey during which coverage was focused on very specific (i.e., small) swaths of seafloor along which known targets were deployed (i.e., search and recovery mode); the goal of this demonstration was not to sweep broad areas of the seafloor looking for unknown targets (i.e., WAA mode). Substantial portions of the three survey days were thus spent searching for suitable water quality conditions and deploying and recovering the target strings and, as a result, were not spent actively collecting LLSS data. Since the cost/hectare is ultimately dependent on daily survey costs, these activities are included in the calculation. As a result, the cost/hectare value is greatly increased for search and recovery.

Since the ultimate goal of this cost assessment is to evaluate the performance of the technology for future full-scale production surveys (i.e., not targeting specific seeded items), the cost/hectare was extrapolated for WAA mode by dividing the total costs for three survey days ($76,800) by the product of survey production rate and the total survey time expected for three WAA survey days (24 hours). An estimate of 8 hours per WAA survey day was used for this calculation assuming a 12-hour working day with 4 hours spent on vessel steam time and turnaround time between passes (no data logged); this parameter could theoretically increase to 20-24 hours assuming round-the-clock operations with some maintenance time, steam time, and turnaround

time. The survey cost/hectare (wide area assessment) value provided in Table 3 ($650) is based on the production rate for a conventional low altitude (4 m) pass.

In contrast to the survey cost/hectare, the cost/survey hour (search and recovery) value provided in Table 3 ($22,100) was calculated as the total cost for three survey days ($76,800) divided by the precise amount of total time spent collecting data over selected target areas (3.5 hours; obtained from the data logging times embedded in the GeoDAS files). Again, this cost is reflective of actual results for the Year 2 survey conducted largely in search and recovery mode; thus time spent not actively collecting LLSS data is not included in the calculation. As a result, this value is also greatly increased relative to WAA mode.

In order to extrapolate the cost/survey hour for WAA mode, the WAA cost/hectare (described above) was multiplied by the production rate. The cost/survey hour (WAA) value provided in Table 3 ($3200) is based on the production rate for a conventional low altitude (4 m) pass.

9.1.5 Demobilization Costs

Demobilization for the LLSS is best described as the inverse of the mobilization. The same manpower and rental equipment is required and the same tasks are performed, just in the opposite order. Thus the costs for the two tasks are assumed to be equal and cost breakdown for demobilization includes the same line items as mobilization (see Section 9.1.3).

For the Year 2 LLSS demonstration, demobilization occurred at the SPAWAR dock on San Diego Bay. The same shoreside crane and welding companies were subcontracted for the equipment breakdown and the same personnel (survey team plus additional staff from the local SAIC facility) performed the dockside equipment preparation and loading. Once again, rentals of both a large forklift and a flatbed truck were required to complete the transport task; although the same exact equipment was used, these rentals were separate from the mobilization (i.e., the equipment was returned during the active survey days and then rented again in order to reduce costs). Unloading, cleaning, and storage of the equipment was then performed at the SAIC Marine Operations facility. The dockside loading and the warehouse unloading tasks were each performed in one day. Finally, the SAIC Newport staff was required to travel home from San Diego.

9.1.6 Survey Product Costs

The survey product costs for the LLSS include personnel hours spent on data processing (i.e., viewing LLSS data in the various software applications), target analysis (i.e., measurements and positioning), survey graphic production (i.e., saving and organizing final target images) and survey reporting (i.e., producing a summary of data collection within one week of the conclusion of survey activities). The cost of the various survey products for the Year 2 LLSS demonstration is provided in Table 3. The products themselves are described in the text of this report.

9.2 COST DRIVERS

The primary cost drivers for the LLSS demonstration were the daily labor costs for the specialized and relatively large staff (six SAIC technicians plus the IXSEA engineer) needed to operate the equipment and the daily charter rate for the survey vessel. Shorter and less complex

surveys could likely be accomplished with less personnel as these operations become more routine.

Although vessels other than the R/V *Acoustic Explorer* are capable of supporting the LLSS technology, any vessel that is contracted must be of sufficient size to physically handle the large winch and generator as well as feature an A-frame large enough to launch the FOCUS vehicle. The vessel charter was arranged by SPAWAR through an existing service contract. Should a large research vessel similar to the R/V *Acoustic Explorer* be chartered from an outside contractor, the daily costs could substantially increase compared to the amount provided for this line item in Table 3. Furthermore, the survey vessel costs incurred for the Year 2 demonstration were based on approximately 12-hour survey days with all personnel returning to shore each night. Should a potential future survey occur offshore with all personnel required to live aboard the survey vessel during operations, the vessel costs would be expected to escalate accordingly, though additional costs for shoreside lodging and per diem would be avoided. Night operations would be recommended for relatively shallow water sites to avoid the effects of ambient light in the water column but would not be a limiting factor for deepwater sites.

In addition to the cost drivers described above, mobilization and demobilization costs must also be factored into the planning of any future demonstrations. As described in Section 9.1.3, the mobilization costs for the Year 2 survey were relatively low since most of the large equipment did not have to be transported far from the SAIC Marine Operations facility in San Diego to the SPAWAR dock on San Diego Bay. Should future surveys occur cross-country or overseas, equipment shipping costs could rise into the tens of thousands of dollars. Any survey occurring outside of San Diego would also require increased travel costs for part of the SAIC staff needed to operate the equipment.

Finally, another cost driver that did not factor into the Year 2 demonstration but that may impact future surveys are recovery costs for maintenance and replacement of the capital equipment. As the present LLSS equipment was manufactured nearly 20 years ago, several digital components are oversized compared to present day equivalents and some replacement parts are difficult to obtain. A newly produced commercial system would be expected to be more reliable and less complex to integrate and operate, thus reducing pressure of this driver. A newer FOCUS vehicle with a smaller footprint and reduced power requirements is currently being evaluated.

9.3 COST BENEFIT

It is difficult to evaluate the cost benefit of the LLSS compared to other marine UXO survey approaches in a traditional sense because no alternative commercial technology exists that is capable of producing a comparable optical-based survey product at a similar production rate suitable for WAA. In terms of simply mapping and identifying targets, the costs for an LLSS survey can be compared to costs for a conventional magnetometer survey using one of several marine magnetometer platforms (e.g., MTA, transverse gradiometer) for anomaly mapping. In terms of producing visual images of targets, LLSS costs can be compared to intrusive investigation and underwater video surveys using either divers or an ROV. Underwater video would produce an optical-based survey product similar to that of the LLSS, but the production rate would be substantially reduced. Each of these alternative approaches would also provide similar quality three-dimensional mapped data files that will support detailed target analyses; creation of survey graphics and GIS documents; and subsequent target relocation, investigation,

and recovery operations. Any comparison between the LLSS and alternative technologies must also assume that potential targets are proud of the seafloor for WAA objectives; otherwise, they would not be detectable by the LLSS.

Table 4 provides the comparative unit costs for the LLSS and alternative UXO survey approaches including the MTA (magnetometer survey to identify magnetic anomalies only), divers (performing intrusive investigation to identify targets following a magnetometer survey) and an ROV (performing remotely controlled excavation to identify targets following a magnetometer survey). The MTA costs were taken as listed from the *Cost and Performance Report for UXO Detection and Characterization in the Marine Environment* (ESTCP Project MR-200324; ESTCP, 2009).

The diver costs were generated from standard SAIC rates for providing a dive team to perform intrusive investigation and underwater videography in a marine offshore environment. These values are based on an estimated daily rate of $18,000 for a six-man dive team (one supervisor, four UXO divers, one UXO safety diver) assuming six magnetic anomalies covering 1 acre of survey area (based on 2.75 linear miles of magnetometer survey) are intrusively investigated per day to a depth of 1 ft below the sediment-water interface, the diving occurs in clear and open water to allow access by divers, and the dive depths do not exceed 30 ft from surface. This daily rate also incorporates joint travel regulations per diem and reflects required overtime labor for diving operations. However, the daily rate for divers could change substantially depending on per diem rates for specific locations, number of dive teams utilized, local rates for boats and support equipment and water conditions at the site. For Table 4, the survey cost/hectare for divers was calculated by dividing the $18,000 daily rate by the one acre (0.4 ha) expected to be covered in that day. In contrast, the cost/survey hour was calculated by dividing the $18,000 daily rate by eight survey hours, assuming a 12 hour work day with four hours spent on steam time and equipment setup.

Finally, the ROV costs are based on competitive bidding for ROV intrusive investigation and underwater video surveys at a marine offshore area.

Table 4. Cost benefit analysis for the LLSS compared to alternative marine UXO survey approaches.

Survey Approach	Survey Cost/Hectare ($K)
LLSS	4.5
MTA (magnetic anomaly mapping only)	1.1
Divers (video and/or intrusive)	45
ROV (video and/or intrusive)	10.0
Note: All unit costs include equipment, personnel, mobilization, demobilization, and planning.	

The information provided in Table 4 shows that the LLSS is more expensive than an MTA magnetometer survey both per hectare and per hour (mainly due to large personnel and survey vessel requirements). It is important to realize, though, that the MTA does not generate real-time visual images of the targets; it only identifies the locations of magnetic anomalies as spikes in the magnetic return.

The LLSS is less expensive and more efficient than a full intrusive or underwater video investigation using divers or an ROV in terms of coverage, but more expensive than these techniques in terms of time. The latter can be explained by the fact that the LLSS has relatively large equipment and personnel requirements, but actual data acquisition (i.e., active survey time) occurs very quickly once the sensor is in the water. Neither divers nor an ROV can generate visual images of the seafloor unless they are accompanied by an underwater camera, but they are typically used to investigate targets in place or recover them for identification at the surface following a magnetometer survey. Since the LLSS can both locate targets and provide visual images of them for identification, this technology can be seen as combining the best aspects of the other approaches into one integrated package. To that end, the per unit area costs associated with the LLSS are less than the costs of the other approaches combined, thus making the LLSS a relatively cost effective and versatile method for underwater UXO characterization.

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10.0 IMPLEMENTATION ISSUES

This section is intended to provide information that will aid in the future implementation of the LLSS technology. It is also meant to describe lessons learned during the demonstration and discuss other pertinent issues such as potential environmental regulations that may apply to the use of the technology, end-user concerns, reservations, and decision-making factors, relevant procurement issues, current availability of the technology, and any specialized skills or training needed to implement the technology. Brief descriptions and references for other documents such as guidance or protocols are provided as appropriate.

10.1 ENVIRONMENTAL CHECKLIST

There were no environmental issues associated with the LLSS demonstration. All operations were nonintrusive and thus did not require permits or ESSs and were not subject to any other local environmental regulations.

10.2 OTHER REGULATORY ISSUES

There were no specific regulatory issues associated with the LLSS demonstration. All activities were overseen by SPAWAR and conducted within the constraints of the project specific Demonstration Plan and HASP, both of which were reviewed and approved by ESTCP and the Navy prior to initiating work. In addition, all activities were conducted within the boundaries of Navy training ranges or other controlled areas (e.g., boat lanes) and were coordinated with the Navy, as required, to obtain clearance and avoid any potential conflicts with ongoing Naval operations. All requests for information, site visits, and formal presentations for this project were coordinated and overseen by the SPAWAR PM.

One regulatory lesson learned during the LLSS demonstration was the concern over whether standard operating procedures and HASPs developed for this project were adequate for laser safety at the site of proposed work (i.e., SCIRC). The connotations associated with the term “laser” are such that all work performed with this type of instrument is often automatically assumed, particularly by the military, to involve some type of cutting, weapons guidance, or other activities capable of inflicting serious bodily harm (e.g., severe burns, blindness), rather than simply producing a visual scan of the seafloor. Therefore additional approvals and special clearance were required on top of those normally expected.

10.3 END USER ISSUES

The most likely end users of this technology are commercial UXO service provider firms under contract to DoD. Direct DoD users include Army, Navy, and Marine Corps installation managers who are responsible for training ranges with marine MEC contamination problems. The results of this demonstration are expected to be of immediate interest to both the Navy and members of the USACE nationwide.

10.4 AVAILABILITY OF THE TECHNOLOGY

The complete LLSS (including FOCUS ROTV) is the property of SAIC and is housed and maintained at the SAIC Marine Operations facility on Ponderosa Avenue, San Diego, CA. It can be made available to support other demonstrations and marine UXO survey operations.

However, the software platforms required to operate the LLSS are property of OIC and must be purchased or rented from them prior to any survey activities. The SAIC image processing software developed for this demonstration is property of SAIC and not available commercially, but this package is only useful for data post-processing and is not required for data acquisition.

10.5 SPECIALIZED SKILLS OR TRAINING

No specialized training is required to operate the LLSS aside from company-specific or project-specific health and safety training for both marine offshore and laser operation. Specialized skills in maintaining and troubleshooting the LLSS, piloting the FOCUS vehicle and operating the LLSS software are required to ensure optimal performance, and these skills can only be acquired through prior work with the LLSS technology. The various members of an LLSS survey team should also possess sufficient skills and experience in oceanography, large boat survey operations, marine navigation, electrical engineering, and software design. If an LLSS survey is to be accompanied by any diver-assisted intrusive or recovery operations, then all divers would be required to possess appropriate commercial diving certifications and any divers potentially characterizing or handling munitions would be required to possess appropriate explosive ordnance disposal training and experience.

11.0 REFERENCES

Environmental Security Technology Certification Program (ESTCP). 2009. Cost and Performance Report. UXO Detection and Characterization in the Marine Environment. ESTCP Project MR-200324. December.

Science Applications International Corporation (SAIC). 2008. Final Report. UXO Detection and Characterization in the Marine Environment. ESTCP Project MR-200324. November.

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APPENDIX A

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APPENDIX A (continued)

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Dale Berlin	Maxim Crane Works, L.P. 6232 Fairmount Ave San Diego, CA 92120	Tel: 619-517-0659 Fax: 619-563-7833 E-mail:dsberlin@maximcrane.com	70-ton Crane Services Vendor
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Kevin Gayken	Hawthorne Lift Systems 10930 Willow Court San Diego, CA 92127	Tel: 858-207-2802 Fax: 858-207-2875 E-mail: Kevin.Gayken@hawthornelift.com	Forklift Rental Vendor
Unknown	Ryder System, Inc. RTR San Diego 5345 Overland Avenue San Diego, CA 92123	Tel: 858-565-4221 Fax: Unknown E-mail: Unknown	Flatbed Truck Rental Vendor
Unknown	Holiday Inn San Diego Bayside 4875 North Harbor Drive San Diego, CA 92106	Tel: 619-224-3621 Fax: 619-224-3629 E-mail: Unknown	Hotel

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